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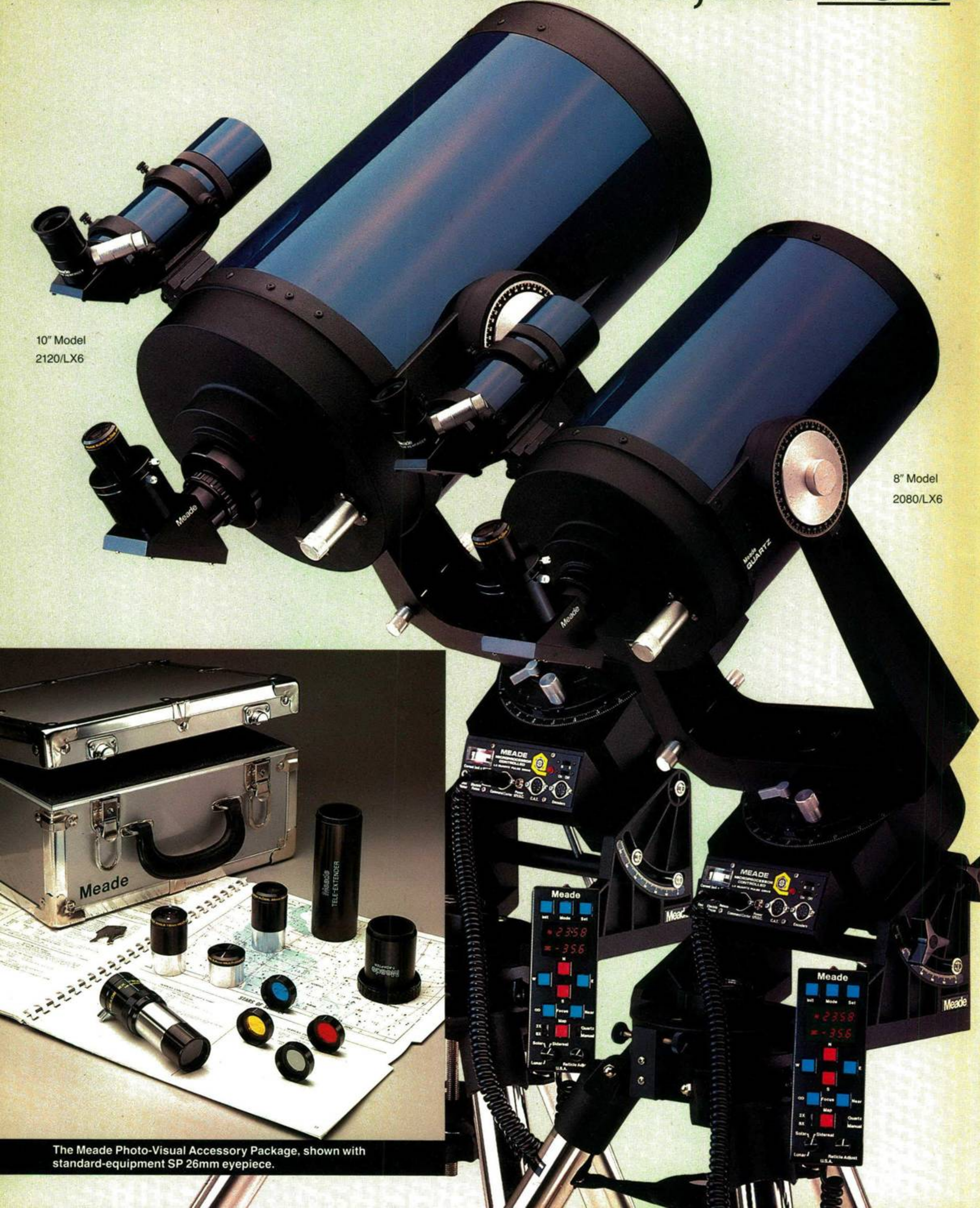
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1—Series 4000 #140 2X Telenegative Barlow Lens. *List price: $120.*

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1—Tele-Extender for eyepiece-projection photography. *List price: $50.*

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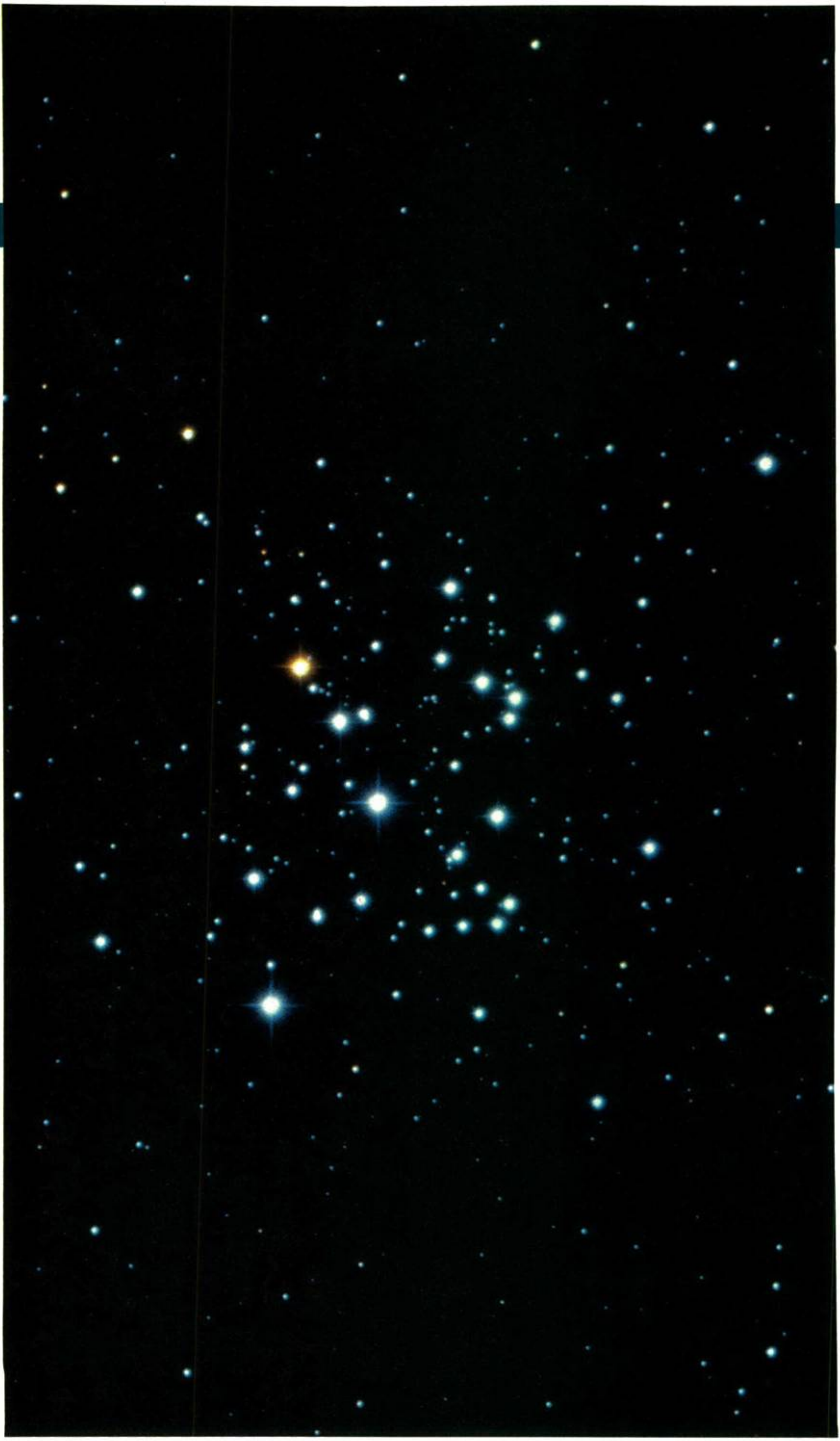
ON THE COVER: Mars wowed observers throughout its 1988 opposition. Backyard telescopes revealed surface markings, dust clouds, and the planet's South Polar Cap. (See page 74.)



RED, ORANGE, WHITE, OR BLUE, a star's color is directly related to its nature. By decoding starlight, astronomers have learned much about the physical properties of stars. The stars in the cluster NGC 3324 in Carina contain mainly young, blue stars. (See page 36.)

ASTRONOMY®

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Behind the Scenes

THE SECRETS OF THE UNIVERSE

The universe holds its secrets close. So distant are the stars and so vast the timescale of their existence that casual examination reveals nothing about them. Indeed, without the accumulation of thousands of years of human culture, hundreds of years of science, decades of theories, and years of new data, we would still know nothing of the stars.

The secrets of stars lurk in starlight, messages coded in spectra and waiting to be deciphered by astronomers. The message of starlight is written in the language of atomic physics; the "secret decoder ring" astronomers use is the spectroscope. It is hard to imagine astronomy without the spectroscope. We would know the positions of the stars in the sky, and we would know the distance to a hundred or so. But we wouldn't know the sizes of the stars, the shape of our Galaxy, or of the existence of other galaxies. Astronomy would be frozen a hundred years back. You'll find our story on what astronomers learn from the colors of starlight on page 36.

Among the stars, brown dwarfs are perhaps the most secretive. Creatures of theory — cool, tiny, dim, and possibly very numerous — brown dwarfs may not even exist. Although astronomers have reasons to think they will find brown dwarfs, they have yet to make a clear-cut find. Because we know brown dwarfs are dim, astronomers expect these stars to be hard to find. You can read about the ongoing search for brown dwarfs on page 18.

Although the "secrets" of telescope design perhaps do not fall in the same class as the mysteries of the stars, amateur astronomers still search for telescopes better suited to the study and enjoyment of the starry firmament. They have succeeded admirably. In the decade since John Dobson's altazimuth design swept the world of amateur astronomy, telescope makers have created larger, lighter systems than ever before. The secrets of the new generation of telescopes are revealed beginning on page 62.

With warm weather now fast approaching most parts of the United States, April is a fine time to begin your personal exploration of the secrets of the night sky. Whether you use a telescope or your unaided eyes, your sense of wonder and the power of your mind are the tools for opening wide the secrets of the stars.

Sincerely,

Richard Berry

Richard Berry
Editor-in-Chief

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Letters

Reasons for Soviet Shuttle

I may have an answer to the question raised in "Do the Soviets Need a Shuttle?" by David S. F. Portree (Space News, January 1989). The key is the capability of returning cargo from space.

The Soviets normally make ninety or more launches per year, and the majority of these are to put up reconnaissance or other military satellites. It appears to me that the Soviet shuttle may be used to retrieve some of these satellites, which usually have lifetimes in orbit of just a few weeks or months before they're burned up in the atmosphere. Retrieving at least the most costly satellites would be a way to save money and resources.

It's also possible that the Soviets may have a military purpose for their shuttle: attempting to retrieve Western satellites that no longer function or are unable to communicate with Earth. — *Edwin Krampitz, Jr., Portsmouth, Virginia*

Space Is a Global Concern

I wish I could understand David S. F. Portree's paranoia about the Soviet Union's desire to have a space shuttle of its own (Space News, January 1989).

Space, as it pertains to us here on Earth, is not the property of any one nation. Considering that we are on the only planet we know of with the intelligence to carry out space investigations, our goals should be global, not taking part in a sport in which individual nations score points.

If Earth had a global space program, the amount of money that could be saved by everyone would be, quite literally, astronomical. — *S. J. Black, Toronto, Ontario, Canada*

Herschel House Worth a Visit

I read with great interest "William Herschel: Pioneer of the Stars" by Brian Jones (November 1988). Your readers might like to know that Herschel's house in Bath, England, is open as a museum, and if they're visiting England, the house is well worth a visit.

I also wanted to add that making telescope mirrors in the eighteenth century was a dangerous practice. The molds were usually made from horse dung, and on one occasion the molten metal, with which Herschel made mirrors, leaked through the bottom of the mold, through the furnace, and into the fire. The flood of hot metal shattered the flagstone floor, and Herschel and his helpers were forced to flee. — *Sean Keep, Reading, Berkshire, England*

Communicating with the ASP

Thank you for mentioning the Astro-

DEAR MR. NAGLER:

Several years ago, I purchased a 10″ Schmidt-Cassegrain telescope. On this new instrument, I carefully compared the performance of the most respected brands of eyepieces before concluding that the **Tele Vue** Plössls were giving me the best views. Along with 4 of your Plössls (55, 26, 17 and 13mm) and your 2.5x Barlow, I bought a Giant Off-Axis Guider, which I frequently use as a telecompressor. Although I have always been pleased with your eyepieces, there are limits to just how much a long-focal-length telescope can be telecompressed! ■

For over three years, I have wanted a second instrument for rich-field observing and photographing. Although your **Renaissance** is most impressive, it just wasn't quite the instrument I wanted and the **Oracle** was a bit too small. Then came **Genesis.** Knowing what a stickler you are for details in both design and production, plus my total satisfaction with your eyepieces; sight unseen, I bought a **Genesis** based solely on those facts and your ads in the magazines. ■

I took delivery of my **Genesis** at the Texas Astronomical Society's meeting on 7/22/88. Even with all the light pollution in that North Dallas parking lot, my new **Tele Vue** 32mm Wide Field eyepiece, at less than 16x, clearly resolved Saturn's rings as separate from the disc. When a friend asked to try his 12 mm Nagler-II with his 3x Barlow, I knew I had bought a "winner." The Cassini Division was as sharply defined as I have ever seen it plus the surface and ring detail was second only to a view I once saw under a Texas Star Party's dark skies through a nearly $20,000, 10.7″ f/15 Maksutov! ■

The reason for this letter is simple. I have now had my first opportunity to take my new **Genesis** out to the T.A.S.'s dark-sky observing site (100 miles north of Dallas). In short order, the **Genesis** had attracted a group of experienced observers (most holding full Messier Certificates) away from their larger telescopes. Simply, **Genesis** stole the show! Except for an occasional comparison view, my 10″ Schmidt-Cassegrain sat idle because I was seeing far greater clarity and detail with my new **Genesis.** Although I had with me a full set of filters (Deep Sky, U.H.C., O-III and H-β), none were ever used. ■

While I had anticipated a gorgeously resplendent Double Cluster, it was truly more dazzling than I expected. But, some real surprises lay ahead. Take M-33 in Triangulum: 4″ just isn't enough aperture for such a diffuse spiral, right? WRONG! With the 32mm Wide Field, I was seeing tremendous detail in a galaxy over 1/3 the width of the field. I could write paragraphs describing a California Nebula covering half the field plus all the glorious sights through Sagittarius and Scorpius like the Lagoon, Trifid and M-21 all in the same field; or, four gleaming globulars, M-22 & 28 with NGC-6638 & 6642. ■

While the Great Andromeda Galaxy (M-31) spread across more than 2/3 of the field, we were all alternating time at the eyepiece, trying to see who could count the most dust lanes. It was more beautiful than even the photographs from the leading observatories. I have never seen M-110 appear as large relative to M-31. One observer even held his hand in front of the eyepiece and suggested that we try observing a projected image! While that may have been beyond even **Genesis'** capability, it does prove we were looking at no dim M-31. There was a debate over which eyepiece provided the better view: the 13mm Nagler's greater contrast and detail or the 32mm Wide Field's greater coverage. Each outperformed the other in its own way and both provided splendid views. ■

All night, comments from seasoned observers included a thesaurus-full of one word expletives of praise, wonder and astonishment. While glued to the eyepiece, other comments included: "... but this is ONLY a 4-inch" to "Boy! You sure made no mistake in buying this one" and "Oh, No!... How am I ever going to make my wife see the need?". One observer even yelled to a friend acoss the field, "Get over here if you want to see what Rich Field is SUPPOSED to look like." Personally, I can hardly wait to start taking astrophotos with it. ■

In case you could have possibly missed my point: I am totally enthralled with my new **Genesis.** Mr. Nagler, what you have created with your **Renaissance** and **Genesis** telescopes has filled a void, beyond binoculars and yet still permitting the beauty of deep sky objects to be viewed 'in context' without resorting to the usual solution of over-magnification that reveals detail at the expense of sacrificing perspective. ■

Because our dark sky observing location attracts late-night dewing and humidity, I appreciate your design consideration of including the fluorite element as a totally internal component, inaccessible to dew, condensation or scratches. ■

It would have been impolite of me not to write and tell you just how much of a Big Bang your **Genesis** telescope has already created in my deep sky observing. ■

Appreciatively yours,

Kent E. Ledlow

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nomical Society of the Pacific's *Tapes of the Night Sky* (Astronomy Products, February 1989). If any of your readers want to order the tapes, our address is: The Astronomical Society of the Pacific, Night Tapes Department, 390 Ashton Avenue, San Francisco, CA 94112. — *Andrew Fraknoi, ASP, San Francisco, California*

The Red Squirrel Has Rights Too

I was shocked to read that the University of Arizona plans to go ahead with building an international observatory on Mount Graham in southeast Arizona, which would be damaging to the habitat of the red squirrel (AstroNews, February 1989).

With all the problems astronomy faces today — light pollution and radio pollution, to name a few — astronomers should appreciate the fact that destroying something for your own gain is not right. — *James Brent, Knoxville, Tennessee*

Astronomy's Geocentric Language

I have given slide lectures to elementary school children on astronomy and space, and I continually come across the heliocentric versus the geocentric problem in the language we use to describe celestial motions.

For instance, we talk about the Moon "coming up in the east," instead of explaining what we see as the result of Earth's rotation. Or we talk about the Sun "moving southward" instead of explaining that the Sun's movement is really a result of the tilt of Earth's Northern Hemisphere.

Adults understand what we mean by phrases like these, but our children don't. We attribute all motions to the Sun or the Moon and not to Earth. We need to correct this geocentric slant of our descriptions of astronomy. — *Chet Twarog, APO, New York*

Correcting 'Fast Films'

I wanted to correct a misunderstanding that appeared in my article "Working against the Grain of Fast Films" (February 1989). It's almost impossible to achieve precise registration by moving the negative, as was stated in the article. The final, exact registration in all the photos used in the article were the result of moving the easel, not the negative. — *Larry Myers, Sacramento, California*

ASTRONOMY welcomes comments, suggestions, corrections, and additional information on articles and astronomy in general. Send your letters to: ASTRONOMY Letters, 1027 North 7th Street, Milwaukee, WI 53233. Letters may be edited for length and clarity. ☐

Viewpoint

THE AMATEUR'S UNIVERSE

by Jack Newton and Philip Teece
Authors of The Guide to Amateur Astronomy, *recently published by Cambridge University Press*

If you were to climb Mount Everest, your effort would bring you to a remote geographic point about five-and-a-half miles above the level at which most of us live. If you were to take a voyage around the world, you would enjoy the experience of islands and cities 10,000 miles distant from your home. Yet the amateur astronomer's explorations can be incomparably more venturesome than these ordinary kinds of exploits.

It is the amateur's joy to encompass the universe in the embrace of a lover.

Astronomy is a voyage of discovery that will last for a lifetime. The geography of this adventure will be virtually boundless. If you come to the telescope with not only a keen eye but with the true power of vision as well, you will be transported far beyond Earth to planets that lie across a deep void of space. And that will be only the threshold. . . .

On a warm summer evening you can relax outdoors and contemplate the starfield with its black gulf suspended above our heads. The closest stars that you see are sufficiently remote from our solar neighborhood that their light has traveled perhaps six or eight years across the interstellar void to reach Earth. The star clouds of the Milky Way — actually dense aggregations of stars in the spiral arms of our Galaxy — are distant background objects several thousands of light-years away from us.

The deep sky has depth, not only in terms of distance but in time as well. In a sense your summer evening vigil is an adventure in time travel. Prominent Deneb, the brightest star in the constellation Cygnus, appears as it actually existed during the final years of the Roman Empire; that is, the era in which the light began its journey to reach us tonight. The glow of the Andromeda Galaxy represents a glimpse into a wholly separate epoch of time, over 2 million years before the dawn of man's recorded history. A small telescope permits a quantum leap farther backward into the depths of time to galaxies that we view as they were 40 million or 50 million years in the past.

In the awesome abyss of space and time, what wonders (and cosmic puzzles) abound, waiting to be encountered by means of binoculars, telescope, and camera? The answer is that there is an entire universe that can be discovered with even the simplest equipment if the observer also possesses the enthusiasm and imagination of the true amateur.

We recently overheard a friend commenting on a certain internationally renowned professional astrophysicist: "In this age of remote control and computer-monitored instrumentation," the critic scoffed, "the man still spends valuable observing time actually visually gazing through the 200-inch telescope. That's amateur stuff."

Precisely! The working scientist, pressed by limited telescope time and the need to yield tangible results in exchange for funding, may find his nose glued to a computer's line printer. By contrast, it is the amateur's joy to encompass the visual universe in the embrace of a lover. His or her principal tool is a keen eye, and the chief reward is a personal delight in the night sky and its splendors.

If you are a beginner, however, don't be intimidated by the specialists' esoteric pursuits and complex gadgetry. Fancy equipment and special observing projects have always remained secondary to the original, simple goal — the thrill of acquiring a growing personal intimacy with the night sky. For a view of many deep-sky objects you need only a dark sky and your unaided eye. Indeed, many of us who have spent half a lifetime with large telescopes and intricate cameras still return frequently to the profound satisfaction of merely scanning the heavens with binoculars or the naked eye.

Perhaps to the amateur astronomer the ultimate attraction in the remote star clouds and galaxies of deep space is their untouchability. We inhabit (we have in fact created) a planet that has become a commercial resource to be consumed and despoiled. Yet our telescopes continue to be the magic carpets by which we can still fly free to wonders of the universe that can never be used, manipulated, or marketed. Their most reassuring attribute is that they lie in regions of space — in an era of time — forever beyond our reach. ☐

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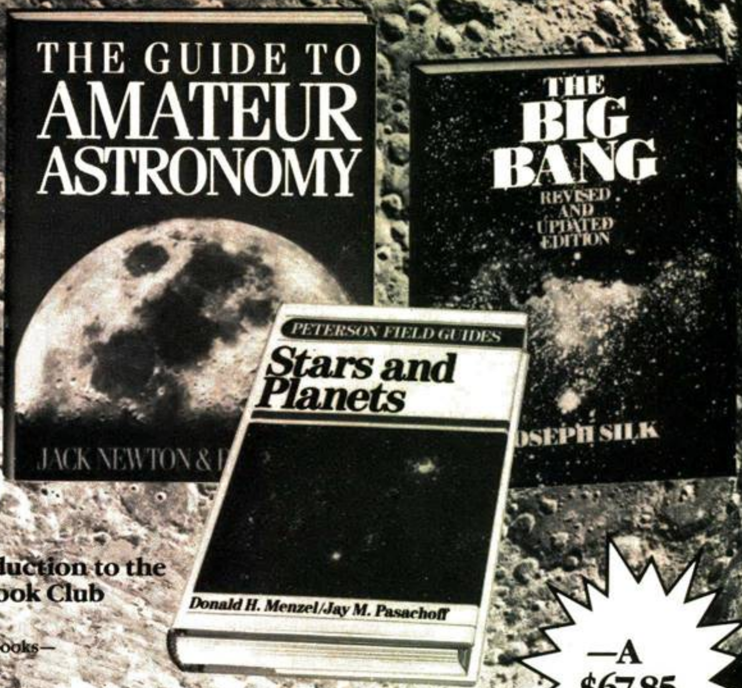
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- What prompted Stephen Hawking to conclude that small black holes may evaporate in the same way that particles did in the early universe?

Viewing the big bang as a continuing—rather than a momentary—event, noted astronomer Joseph Silk traces the life of the universe from its earliest moments. He critically describes the latest cosmological findings as he explains how big bang theory helps you understand the nature of the universe. Publisher's price: $24.95

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Astronomy 4/89

'BLACK WIDOW' PULSAR SHOCKS NEIGHBORHOOD

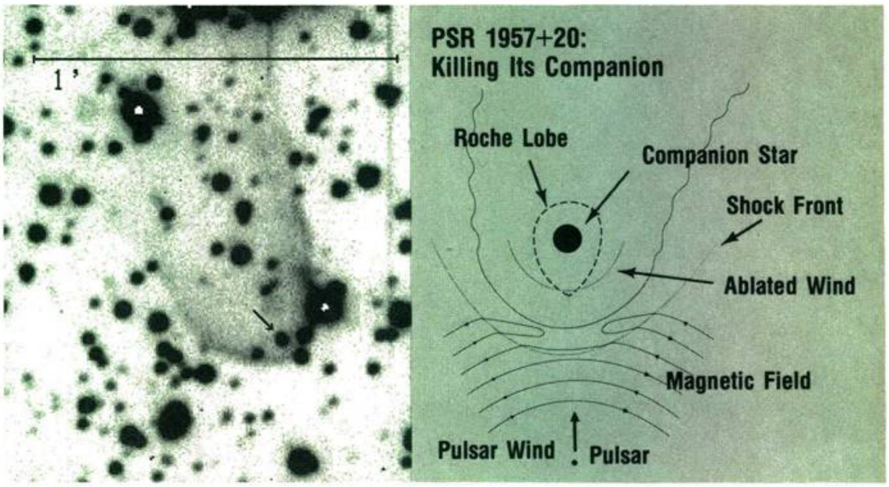
Interstellar gas around the millisecond pulsar 1957+20 glows because a hot "pulsar wind" from the neutron star excites it, claim astronomers Andrew Fruchter and Jeff Hester of Princeton University. The nebula glows where hot gas streaming away from the pulsar collides with the surrounding gas.

The pulsar has been nicknamed the "Black Widow" pulsar because the energetic neutron star is rapidly consuming a small companion star that orbits it. (See "Pulsar Eroding Companion Star," AstroNews, February 1989, and "On the Trail of Exotic Pulsars" by Gerrit Verschuur, December 1988.) Pulsar 1957+20 emits thirty times as much energy as the Sun from a volume only 14 miles across as it spins 600 times per second.

Most of the pulsar's energy comes off as subatomic particles with energies of a trillion electron volts traveling at very nearly the speed of light. The companion, thought once to have been a far more massive star, "spun up" the pulsar when it passed through its own red-giant phase and rained hydrogen onto the neutron star. Rejuvenated by the infalling material, the pulsar became highly energetic.

Heated to 5000 kelvins on the side facing the neutron star, the companion star's surface material is blown into space and accelerated to a high velocity. It spirals outward from the companion until it slams into the interstellar medium and causes the nebula to glow.

Astronomers think that pulsar 1957+20 is the "missing link" between x-ray binary stars and solitary millisecond pulsars. In the x-ray binary, material from the companion star falls onto the neutron star and spins it up, energizing the neutron star. Rejuvenated, the neutron star then destroys its companion by evaporating it.



THIRTY TIMES THE SUN'S ENERGY streams from pulsar 1957+20 in an intense "wind" of energetic particles. The outflow shocks the interstellar medium and causes the nebula to glow.

GALAXIES FOUND IN COSMIC VOID

With data obtained by the *Infrared Astronomical Satellite*, two astronomers from the University of Michigan have discovered five galaxies in the Bootes Void, a region of space thought to be devoid of matter. The questions that must now be answered are: how many galaxies exist in this and other voids and are these estranged galaxies more representative of the mass in the universe than the gregarious galaxies we see in clusters?

Greg D. Bothun and Greg Aldering announced their findings at the January meeting of the American Astronomical Society in Boston. Confirmation of the discovery comes from observations by Robert P. Kirshner with the 172-inch Multiple-Mirror Telescope on Mount Hopkins in Arizona.

The galaxies had not been observed before because they are optically faint. Known as *IRAS* galaxies, their starlight is dimmed by excessive dust, so they radiate most of their energy in the far infrared. Roughly 25 percent of the galaxies located in low-density areas of the universe are *IRAS* galaxies.

The Bootes Void is a vast hollow region around which optically bright galaxies cluster. Though it lies at a distance of about 1 billion light-years from Earth, the Bootes Void covers about 30° of the sky. Its volume is estimated to be 30 billion, billion cubic light-years, so the Bootes Void is a very large place.

But maybe not an empty place. Of a total of thirteen galaxies surveyed by Bothun and Aldering in the direction of the Bootes Void, five turned out to have redshifts that placed them in the void. Astronomers believe this is a high percentage of detections if the void were truly as large as claimed.

According to Bothun, their findings may have important implications for measuring the total mass in the universe. "Our results indicate that previous attempts to map out the galaxy distribution using only visible-light techniques may not provide a satisfactory description of the real mass distribution in the universe," said Bothun.

Most assessments of matter in the universe have taken into account mainly the visible galaxies. These assessments have shown, however, that not enough mass exists to "close the universe," that is, to make the universe dense enough so the gravitational attraction of all the galaxies would eventually halt cosmic expansion. However, the discovery of significant amounts of matter in a region of space thought empty of matter would suggest that *IRAS* galaxies may be the dominant tracers of mass in the universe.

"We need to make more sensitive and complete surveys to find out if this discovery is an accident or a generic feature of the universe," said Kirshner.

As if in answer to this request, Patricia Henning and Frank Kerr of the University of Maryland announced at the same AAS meeting that a radio search for neutral hydrogen sources with Green Bank's late 300-foot radio telescope turned up at least one object along the "back wall" of a void located north of the constellation Pegasus. The radio spectrum of this object, Henning reported, "shows a classic signature of a spiral galaxy — a rotating disk of hydrogen."

MOUNT WILSON INSTITUTE TO OPERATE OBSERVATORY

The Mount Wilson Observatory, operated since 1904 by the Carnegie Institution of Washington, is now administered by the Mount Wilson Institute. The two

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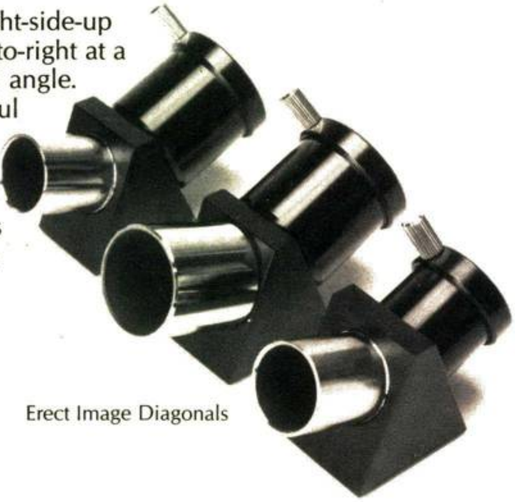

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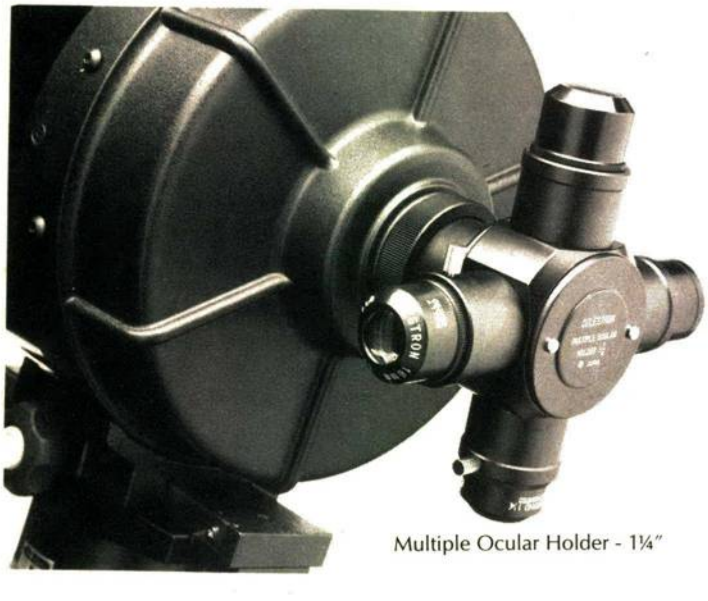
The Multiple Ocular Holder (MOH) allows you to mount up to four oculars at once and rotate between them—smoothly, quickly and precisely. It's particularly valuable for use in cold weather; there's no need to remove your gloves to change cold eyepieces.

Two models are available—.96″ and 1¼″. Each holds four oculars of the same respective barrel size. Both have step rings that allow them to mount directly to the Universal Celestron threads on the rear of the C8, C11 or C14. Either can be mounted on the Celestron C90 series scopes using the Large Accessory Ring. Use with eyepiece filters too!



Multiple Ocular Holder - 1¼″

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Looking for a top-rate binocular to complement your telescope? Celestron has 3 series of mid-size binoculars perfect for sky gazing by night and crystal clear terrestrial viewing by day. These binoculars are made to the same exacting specifications as our telescopes. Every binocular is sealed against dust, and like our telescopes, collimated on a precision laser collimator.

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Every Celestron binocular provides you with high contrast, sharp images edge-to-edge and excellent light gathering ability. Precision assembly and attention to detail by our craftspeople ensure that ghost imaging, scattered light distortion and color fringing are eliminated. It is this superior assembly that guarantees hour after hour of comfortable use.

7x42 Ultima Binocular

Classical Series—7x35, 7x50, 10x50, 7-21x Triple Zoom

Relatively high magnification with an exceptionally wide field of view.

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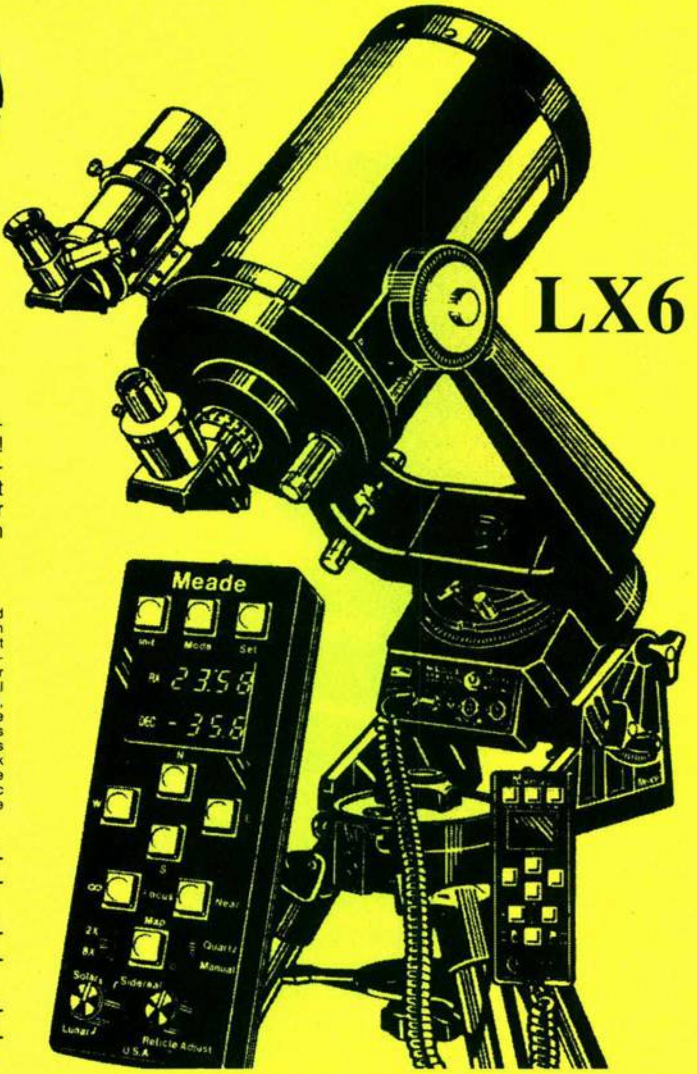

Meade's new LX6's boast an *f*/6.3 optical system which permits astrographic exposures in only four-tenths of the time required by an *f*/10 system! In addition, they come complete with quartz-locked, micro-computer-controlled, electronic pulse-motor drive, sophisticated hand control unit with astrographic drive correction functions built-in, 2.00" star diagonal for advanced, premium-grade eyepieces, giant 9x60mm finderscope, built-in provision for optional digital readouts or CAT system, and much more!

STANDARD FEATURES & FACTORY-SPECIFIED EQUIP:

Complete *f*/6.3 telescope tube assembly (8" or 10" aperture, 1,280mm or 1,600mm focal length), with certified diffraction-limited optical system; MCOG ("Multi-Coated Optics Group"), consisting of multi-layer anti-reflection coatings on corrector plate and enhanced reflectivity mirrors; ultra-smooth anti-backlash focus mechanism; giant 9x60mm illuminated-reticle polar-alignment viewfinder with quick-disconnect mounting bracket; 2.00" mirror-type star diagonal, with 1/10 wave multi-coated mirror and adapter for 1.25" eyepieces; Series 4000 26mm Super Plossl eyepiece, 1.25" (49x or 62x); rugged dual-fork astronomical mount with graduated setting circles, manual positioning controls and clutches on both axes of motion; digital quartz-locked, micro-computer-controlled, electronic sidereal-rate pulse-motor drive system and ultra-precision "LX" worm-drive gearing built into telescope drive base; Power Control Panel (also built into drive base) with controls, indicators and connectors for various accessory and auxiliary electronic equipment; Electronic Command Center hand-control unit (note: Meade's Digital Readout System is an ***optional*** accessory); 115Vac/60Hz power adapter with 25 ft. cord; DC battery-pack *(batteries not included)* with 4 ft. cord; 25 ft. DC power cord with automobile cigarette-lighter plug; Deluxe Equatorial Wedge with micrometric adjusters for latitude and azimuth, latitude scale, bubble level and magnetic compass; ultra-rigid adjustable-height Field Tripod; dust covers for optical apertures; foam-lined carrying case for scope-tube/fork-mount/drive-base assembly; instruction manual; limited lifetime warranty.

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2120 LX6	(List: $ 6,400)	CALL
Optional Digital Readout System:		
Mod. 9068, *for* 2080 LX6	(List: $ 590)	CALL
Mod. 9070, *for* 2120 LX6	(List: $ 590)	CALL
Package: Telescope *and* Optional Digital Readout System, together:		
2080 LX6 *with* Mod. 9068	(List: $4,990)	CALL
2120 LX6 *with* Mod. 9070	(List: $6,990)	CALL

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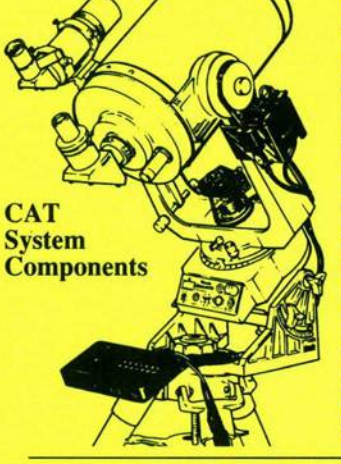
Meade's Computer-Aided Telescope System

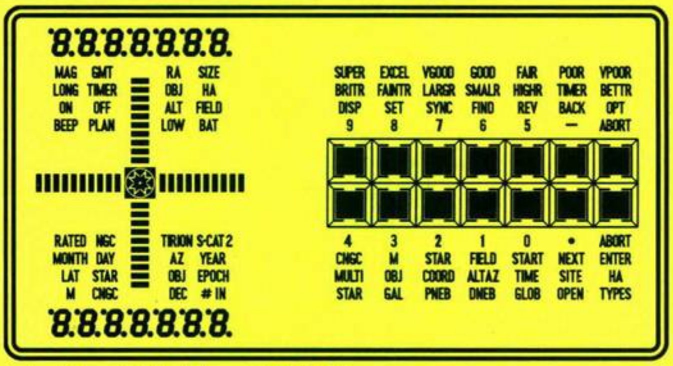


CAT
System
Components

Meade's Computer-Aidea Telescope (the "CAT") system has most of the advantages of a computer-controlled telescope at only a fraction of the cost. Consisting of a specially-designed, high-speed, extremely powerful computer, along with a pair of high-resolution incremental shaft encoders and their associated mounting hardware, drive components and cabling (*see general arrangement drawing at left, and panel layout drawing at right*), the CAT can readily and quickly direct you to any of the thousands of celestial objects whose coordinates and other descriptive information are permanently stored in its 1Mb plug-in EPROM database, ***including all of the planets***, as well as to any other celestial object of known coordinates (comets, asteroids, quasars, super-novae, etc.). The computer is loaded with extra features and functionality as the panel legends, at right, indicate.

For the computer-literate, there is also a version of the CAT available with an RS-232C port (the "CAT-COM") for connection to a "PC" compatible personal computer. CAT-COM includes four "demonstration" software subroutines, written in BASIC, to show you how to address and control the CAT from your own computer, as well as the necessary RS-232C interconnect cable. The software is supplied on a 5.25" 360Kby diskette, with backup source-code listings in the instruction manual.

The CAT is available for most fork-mounted Schmidt-Cassegrain telescopes, but has been ***electronically integrated*** with the new LX6 series, so that the encoders and the CAT computer plug directly into the drive-base. Consequently, during our introduction of the LX6 series telescopes, we are offering extra savings on packages consisting of an LX6 telescope and one or the other of the CAT systems.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Optional Computer-Aided Telescope (CAT) System:		
CAT *for* 2080 *or* 2120 LX6	(List: $1,990)	CALL
CAT-COM *for* 2080 *or* 2120 LX6	(List: $2,290)	CALL
Package: Telescope *and* Optional CAT System, together:		
2080 LX6 *with* CAT	(List: $6,390)	CALL
2080 LX6 *with* CAT-COM	(List: $6,690)	CALL
2120 LX6 *with* CAT	(List: $8,390)	CALL
2120 LX6 *with* CAT-COM	(List: $8,690)	CALL
Hardcopy Listing of CAT Database	(List: $ 60)	CALL

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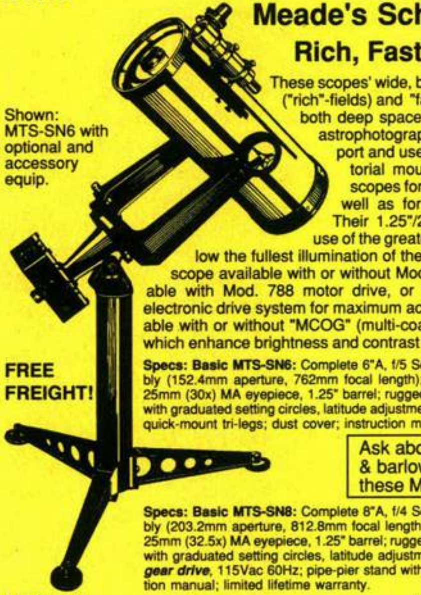

Shown: MTS-SN6 with optional and accessory equip.

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Meade's Schmidt-Newtonians

Rich, Fast and Photographic!

These scopes' wide, bright, highly corrected fields of view ("rich"-fields) and "fast" focal ratios make them ideal for both deep space visual observing and prime focus astrophotography. Easy and convenient to transport and use because of their "fork" -type equatorial mounts, they are excellent all-around scopes for those just starting in astronomy, as well as for experienced astrophotographers. Their 1.25"/2.00" focusers not only permit the use of the greatest variety of eyepieces, but also allow the fullest illumination of the film-plane during photography. 6" scope available with or without Mod. 788 motor drive. 8" scope available with Mod. 788 motor drive, or "LX3" quartz-synchronized micro-electronic drive system for maximum accuracy and precision. All are available with or without "MCOG" (multi-coated optics group) optical coatings, which enhance brightness and contrast of visual and photographic images.

Specs: Basic MTS-SN6: Complete 6"A, f/5 Schmidt-Newtonian telescope tube assembly (152.4mm aperture, 762mm focal length); 2" helicoid focuser, with 1.25" adapter; 25mm (30x) MA eyepiece, 1.25" barrel; rugged dual-fork equatorial astronomical mount with graduated setting circles, latitude adjustment, and latitude scale; pipe-pier stand with quick-mount tri-legs; dust cover; instruction manual; limited lifetime warranty.

Ask about our special finderscope & barlow Accessory Packages for these MTS Schmidt-Newtonians

Specs: Basic MTS-SN8: Complete 8"A, f/4 Schmidt-Newtonian telescope tube assembly (203.2mm aperture, 812.8mm focal length); 2" helicoid focuser, with 1.25" adapter; 25mm (32.5x) MA eyepiece, 1.25" barrel; rugged dual-fork equatorial astronomical mount with graduated setting circles, latitude adjustment, and latitude scale; Mod. 788 ***worm-gear drive***, 115Vac 60Hz; pipe-pier stand with quick-mount tri-legs; dust cover; instruction manual; limited lifetime warranty.

MTS-SN6	(List: $ 1,050)	CALL
MTS-SN6, MCOG	(List: $ 1,130)	CALL
MTS-SN6, 788 MtrDrv	(List: $ 1,200)	CALL
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MTS-SN8, LX3 MtrDrv	(List: $ 1,800)	CALL
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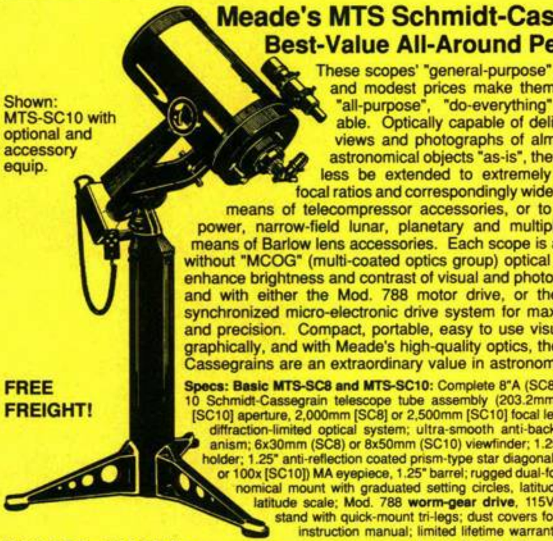

Shown: MTS-SC10 with optional and accessory equip.

FREE FREIGHT!

Meade's MTS Schmidt-Cassegrains

Best-Value All-Around Performers!

These scopes' "general-purpose" f/10 focal ratios and modest prices make them the best-value "all-purpose", "do-everything" scopes available. Optically capable of delivering exquisite views and photographs of almost all types of astronomical objects "as-is", they may nevertheless be extended to extremely "fast" effective focal ratios and correspondingly wide fields of view by means of telecompressor accessories, or to extremely high power, narrow-field lunar, planetary and multiple-star work by means of Barlow lens accessories. Each scope is available with or without "MCOG" (multi-coated optics group) optical coatings, which enhance brightness and contrast of visual and photographic images, and with either the Mod. 788 motor drive, or the "LX3" quartz-synchronized micro-electronic drive system for maximum accuracy and precision. Compact, portable, easy to use visually and photographically, and with Meade's high-quality optics, the MTS Schmidt-Cassegrains are an extraordinary value in astronomical telescopes.

Specs: Basic MTS-SC8 and MTS-SC10: Complete 8"A (SC8) or 10"A (SC10) f/10 Schmidt-Cassegrain telescope tube assembly (203.2mm [SC8] or 254mm [SC10] aperture, 2,000mm [SC8] or 2,500mm [SC10] focal length), with certified diffraction-limited optical system; ultra-smooth anti-backlash focus mechanism; 6x30mm (SC8) or 8x50mm (SC10) viewfinder; 1.25" visual accessory holder; 1.25" anti-reflection coated prism-type star diagonal; 25mm (80x [SC8] or 100x [SC10]) MA eyepiece, 1.25" barrel; rugged dual-fork equatorial astronomical mount with graduated setting circles, latitude adjustment; and latitude scale; Mod. 788 **worm-gear drive**, 115Vac 60Hz; pipe-pier stand with quick-mount tri-legs; dust covers for optical apertures; instruction manual; limited lifetime warranty.

MTS-SC8, 788 MtrDrv	(List: $ 1,800)	CALL
MTS-SC8, 788 MtrDrv, MCOG	(List: $ 1,890)	CALL
MTS-SC8, LX3 MtrDrv	(List: $ 2,150)	CALL
MTS-SC8, LX3 MtrDrv, MCOG	(List: $ 2,240)	CALL
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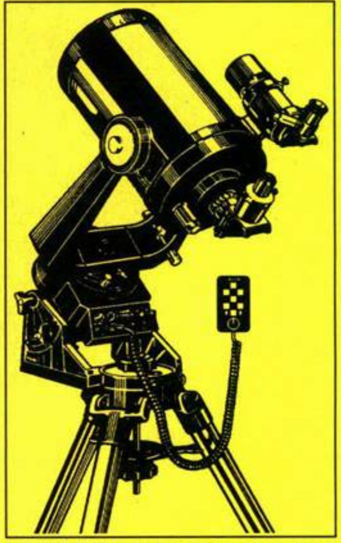
MTS-SC10, 788 MtrDrv, MCOG	(List: $ 2,950)	CALL
MTS-SC10, LX3 MtrDrv	(List: $ 3,180)	CALL
MTS-SC10, LX3 MtrDrv, MCOG	(List: $ 3,350)	CALL



Meade's LX5's

Fully equal to LX6's in terms of their standard equipment, they come complete with quartz-lock microelectronic pulse motor drive, sophisticated hand control unit with photographic drive correction functions built-in, 2.00" star diagonal for advanced, premium-grade eyepieces, & giant 9x60mm finderscope!

Specs: 2080/LX5 and 2120/LX5: Complete 8"A (2080/LX5) or 10"A (2120/LX5) f/10 Schmidt-Cassegrain telescope tube assembly (203.2mm or 254mm aperture, 2,000mm or 2,500mm focal length), with certified diffraction-limited optical system; MCOG ("Multi-Coated Optics Group"), consisting of multi-layer anti-reflection coatings on corrector plate and enhanced reflectivity mirrors; ultra-smooth anti-backlash focus mechanism; giant 9x60mm illuminated-reticle polar-alignment viewfinder with quick-disconnect mounting bracket; 2.00" mirror-type star diagonal, with 1/10 wave multi-coated mirror and adapter for 1.25" eyepieces; Series 4000 26mm Super Plossl eyepiece, 1.25" (77x or 96x); rugged dual-fork astronomical mount with graduated setting circles, manual positioning controls and clutches on both axes of motion; digital quartz micro-electronic sidereal-rate pulse-motor drive system and ultra-precision "LX" worm-drive gearing built into telescope drive base; Power Control Panel (also built into drive base) with controls, indicators and connectors for various accessory and auxiliary electronic equipment; Electronic Command Center hand-control unit; 115Vac 60Hz AC power adapter with 25 ft. cord; DC battery-pack *(batteries not included)* with 4 ft. cord; 25 ft. DC power cord with automobile cigarette-lighter plug; Deluxe Equatorial Wedge with micrometric adjusters for latitude and azimuth (polar-alignment adjustments), latitude scale, bubble level, magnetic compass (and no-tool knob set on 8" scope only); ultra-rigid adjustable-height Field Tripod; dust covers for optical apertures; foam-lined carrying case for scope-tube/fork-mount/drive-base assembly; audio cassette instructions; instruction manual; limited lifetime warranty.

2080/LX5, MCOG, Wedge, Tripod (as above)	(List: $ 3,800)	CALL
2120/LX5, MCOG, Wedge, Tripod (as above)	(List: $ 5,400)	CALL

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Meade's LX3's - Still Going STRONG!

Specs: 2080/LX3 and 2120/LX3: Complete 8"A (2080/LX3) or 10"A (2120/LX3) f/10 Schmidt-Cassegrain telescope tube assembly (203.2mm or 254mm aperture, 2,000mm or 2,500mm focal length), with certified diffraction-limited optical system; MCOG ("Multi-Coated Optics Group"), consisting of multi-layer anti-reflection coatings on corrector plate and enhanced reflectivity (multi-layer over-coated) mirrors; ultra-smooth anti-backlash focus mechanism; large 8x50mm viewfinder; 1.25" visual back (eyepiece holder); 1.25" prism-type star diagonal, anti-reflection coated; 25mm (80x or 100x) MA eyepiece, 1.25" barrel; rugged dual-fork astronomical mount with graduated setting circles, manual positioning controls and clutches on both axes of motion; quartz micro-electronic sidereal-rate drive system and ultra-precision "LX" worm-drive gearing built into telescope drive base; Power Control Panel (also built into drive base) with controls, indicators and connectors for various accessory and auxiliary electronic equipment; Electronic Command Center hand-control unit **(10" 2120/LX3 only)**; 115Vac 60Hz AC power adapter with 25 ft. cord; 25 ft. DC power cord w/cigarette-lighter plug; Deluxe Equatorial Wedge with micrometric adjusters for latitude and azimuth (polar-alignment adjustments), latitude scale, bubble level and magnetic compass (and no-tool knob set on 8" scope only); ultra-rigid adjustable-height Field Tripod; dust covers for optical apertures; foam-lined carrying case for scope-tube/fork-mount/drive-base assembly; instruction manual; limited lifetime warranty.

2080/LX3, MCOG, Wedge, Tripod (as above)	(List: $ 3,520)	CALL
2120/LX3, MCOG, Wedge, Tripod (as above)	(List: $ 5,200)	CALL

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The COMPUTER-AIDED TELESCOPE System
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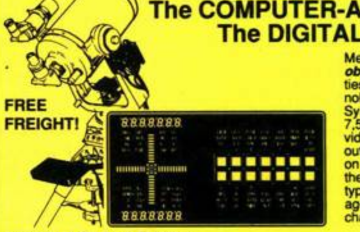

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Meade's "CAT" and "DSC" Systems enhance your ***observing*** pleasure by virtually eliminating the difficulties of "finding". Sophisticated micro-computer technology and software make it possible! The CAT System (at left), contains an internal catalog of over 7,500 astronomical objects. The DSC System provides precise, digital coordinate readout too, but without the internal catalog. Both systems are easy, bolt-on retrofits - no drilling or tapping required. A variant of the CAT ("CAT-COM") can communicate with a PC-type computer (see opposite page for details). Package pricing is available when either System is purchased at the same time as its telescope (not for MTS).

Individual System Pricing:

DSC Sys., for 2080, 2120, C8 or C11	(List: $ 700)	CALL
CAT Sys., for 2080, 2120, C8 or C11	(List: $ 1,990)	CALL
CAT-COM, for 2080, 2120, C8 or C11	(List: $ 2,290)	CALL

Package Pricing (Electronics System purchased at same time as its telescope):

DSC Sys., for 2080, 2120, C8 or C11	(List: $ 700)	CALL
CAT Sys., for 2080, 2120, C8 or C11	(List: $ 1,990)	CALL
CAT-COM, for 2080, 2120, C8 or C11	(List: $ 2,290)	CALL

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organizations jointly announced the transfer on January 5. (See "Renaissance on Mount Wilson" by Richard Berry, April 1988.)

The five major research programs now in operation at the observatory will continue under the new management. These include regular observations at the 60-inch reflector telescope and at the 150-foot and 60-foot solar tower telescopes. The Mount Wilson Institute will also work toward the orderly recommissioning of the 100-inch Hooker telescope (moth-balled since 1985) and will initiate new scientific and educational activities at the observatory.

The Carnegie Institution will retain title to the observatory's facilities for an interim period of two years and will remain as lessee under the U.S. Forest Service lease. Carnegie expects to transfer its ownership and lease rights to the institute at the end of this period.

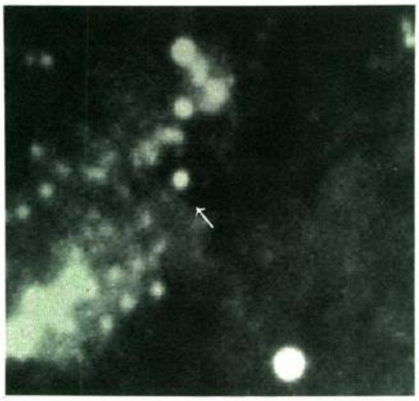
"Emphasis for future research is likely to be on the possible detection of planets around other stars," stated Arthur H. Vaughn, chief executive officer responsible for science and policy matters, "and studies of stellar interiors by helioseismology." Under Vaughn, the Mount Wilson Institute will develop specific science objectives for the 100-inch. Vaughn stated that the availablity of the 100-inch telescope would revolutionize these fields of astronomy.

The Mount Wilson Institute plans to initiate other new astronomical research at the observatory. One such project may be an automated photoelectric telescope (see "Thinking Telescopes" by Richard Berry, August 1988) that the Smithsonian Astrophysical Observatory would use for automatic observations of long-term stellar phenomena, such as star spots.

REMNANTS OF TWO FAMOUS SUPERNOVAE LOCATED

Astronomers have detected the remains of two supernovae witnessed decades ago by Earth-bound observers. The discoveries mark the first time in the history of modern astronomy that astronomers have seen optically both a supernova explosion and the resulting supernova remnant.

The first remnant discovered was of a star that exploded thirty-two years ago in the nearby spiral galaxy M83 in Hydra. Designated 1957D, the supernova faded rapidly after its initial outburst and had not been seen by optical astronomers since. Now Knox Long and William Blair of Johns Hopkins University and Wojciech Krzeminski of Las Campanas Observatory have found the optical remains of the explosion with the 2.5-meter Dupont telescope at Las Campanas Observatory in La Serena, Chile. They reported their discovery at the January meeting of the American Astronomical Society held in Boston.



GLOWING BRIGHTLY in visible light, the remnant of supernova 1957D is the youngest ever discovered optically.

Not only is this the first time astronomers have observed both a supernova and its remnant at visible wavelengths, this is also the youngest supernova remnant ever located optically. The remnant is just one tenth as old as the youngest remnant in our own Galaxy, that of Cassiopeia A (see "Supernova Aftermath" by Laurence A. Marschall, February 1989).

The second discovery is a remnant of one of the most celebrated supernovae in history, one that played an important role in the debate over how far away the spiral nebulae are. The supernova S Andromedae exploded in the Andromeda galaxy in 1885 — the only recorded supernova in our galactic neighbor — and was barely visible to the naked-eye.

Using the 4-meter telescope at Kitt Peak National Observatory, a team of astronomers from the University of Colorado in Boulder photographed the nucleus of the Andromeda galaxy. S Andromedae occurred on the side of the galaxy nearest Earth, and the astronomers did not try to locate the remnant's faint glow against the glare of the galaxy's nucleus. Instead, they looked in a portion of the visible spectrum where iron atoms strongly absorb light.

What they found was a dark spot approximately 1 light-year in diameter silhouetted against the galaxy's nucleus. The large amount of iron in the remnant indicates that the progenitor was most likely a white dwarf. As such, the remains allow astronomers to study the nature and chemical composition of the original explosion, even though it occurred more than a century ago.

Space News

TAKING THE NEXT 'GIANT LEAP'

It is the official space policy of the United States to "expand human presence beyond Earth orbit into the solar system." But just how the country should go about accomplishing this is an open and contentious question. Should we make a leap straight to Mars or take smaller steps to the Moon?

A yearlong study of this problem was recently completed by NASA's Office of Exploration. Four different approaches were selected representing a range of possible missions, from the ambitious to the conservative. The goal of the study was not to select a single approach but to learn more about the problem by studying it from several angles.

Two of the scenarios were "expeditions" that would send astronauts directly to Mars for brief stays. One would send a crew of four to explore the surface of Phobos and to operate from Mars orbit a suite of scientific instruments on the surface, including a sample-return rover. The crew would spend thirty days in the Martian system before returning to Earth. The Phobos expedition would not require an advanced transportation depot in Earth orbit for assembly.

The ultimate expedition to Mars —three back-to-back trips that would put four astronauts on the surface for twenty-day stays and others on Phobos and Deimos — was judged to be impractical. This scenario was extremely costly, requiring up to twenty launches to assemble the spacecraft for each trip.

Two other scenarios looked at ways to move toward Mars by first building facilities on the Moon. The more modest of these was a human-tended astronomical observatory on the lunar far side that would also serve as a base for geologic exploration. Only four trips would be

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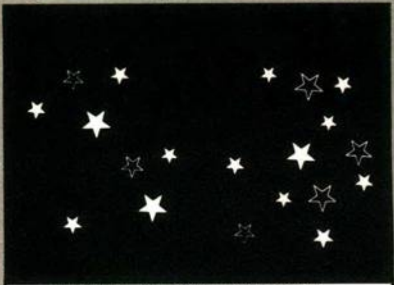
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FREE DEMONSTRATIONS

required to set up the observatory and one per year to maintain it.

A permanently staffed base on the Moon was also studied as a direct precursor to a base on Mars. The lunar base would mine liquid oxygen from the lunar soil for breathing and propulsion. After the lunar base had achieved self-sufficiency, an outpost would be established on Mars and fuel plants would be built on the Martian moons. A four-person crew would stay on Mars for as long as a year.

The Office of Exploration is studying these and other scenarios in more detail this year. NASA hopes to present specific mission scenarios to the president in the early 1990s.

SOLAR MAX *SATELLITE WON'T BE SAVED*

The *Solar Maximum Mission* will not get a third lease on life. The satellite that was repaired in orbit by the space shuttle in 1984 will not get a boost by the shuttle to prevent it from re-entering the atmosphere next year. (See "Will *Solar Max* Be Saved?" by Gerrit L. Verschuur, October 1988.)

Lennard A. Fisk, NASA associate administrator for space science and applications, made the decision in December to terminate preparations for a shuttle rescue mission. In making this decision, Fisk cited budgetary constraints and the high priority of missions already on the shuttle that would have to be displaced for a rescue effort.

CELEBRATING VOYAGER'S *NEPTUNE ENCOUNTER*

The Planetary Society is sponsoring *Voyager* Watch events this summer to celebrate *Voyager 2*'s encounter with Neptune in August. Astronomy clubs throughout the country can obtain *Voyager* videotapes and written materials from the Planetary Society to use in their own celebrations of the encounter.

Voyager Watch activities will culminate on August 23-27 during the *Voyager* encounter with Neptune. The Planetary Society will then be holding Planetfest '89 in Pasadena, California, which will feature Soviet-American astronomical art, lectures, films, and live *Voyager* images of Neptune and Triton.

If you're interested in sponsoring *Voyager* Watch events, contact the Planetary Society, 65 North Catalina Avenue, Pasadena, CA 91106, or phone (818) 793-5100.

Amateur News

MICHIGAN LIGHT VICTORY

Astronomers at the John Rogers Observatory in Traverse City, Michigan, are celebrating a victory over light pollution. Last autumn astronomers from the observatory, which is part of Northwestern Michigan College, convinced a nearby local power company to shut off its lighting at night and two other nearby power companies to reduce nighttime lighting. Light pollution opponents see the Michigan case as a textbook example of how local media influence can thwart light pollution around observatories.

"Right now we've turned everything off," said John Hadder, community services director for Consumers Power Company in Traverse City. A Consumers Power substation, located just a quarter mile from the observatory, turned off its night lighting after an editorial that appeared in the *Traverse City Record-Eagle* pointed out the damage scattered light was causing.

Following Consumers' lead, two substations to the south jointly operated by Wolverine Power Supply Cooperative and Traverse City Light and Power cut their night lighting substantially. "We were completely unaware of being the source of any problem," said Hadder.

The city's awareness of light pollution began months before. Upset by the power company's dazzling halo of light, local astronomy buffs had for months dubbed the pollution the "Consumers Nebula."

"You don't know what a problem it's been," said Dick Cookman, astronomy professor at Northwestern Michigan. "The observatory's view toward the northern, northwestern, and western horizon was pretty well shot. We never thought anything could be done about it."

Once astronomers spread the word, however, they discovered how easily they could eliminate the problem. Astronomers at the observatory hope their victory can help inspire other communities to cut back on unnecessary light aimed skyward.

MOONWATCH II SCHEDULED

"April 6, 1989, presents an excellent opportunity for spotting a very young crescent Moon," according to Brad Schaefer of NASA's Goddard Space Flight Center. For the second year in a row Schaefer and LeRoy E. Doggett of the U.S. Naval Observatory are operating a Moonwatch program.

"We're interested in reports from observers who glimpse the young Moon on the night of the 6th," said Schaefer. "Observers should have a clear western horizon and begin searching for the Moon about thirty minutes after sunset."

Even if you do not see the Moon, send a short report. Include your name, observing location, and whether or not you saw the Moon. Send the reports to: Moonwatch, Nautical Almanac Office, U.S. Naval Observatory, Washington, DC 20392. ☐

REDUCED LIGHT POLLUTION resulted when a *power company (in background)* near the Joseph Rogers Observatory in northern Michigan agreed to minimize its lighting at night. (The streak at center was caused by a meteor.) Photo by John L. Russell.

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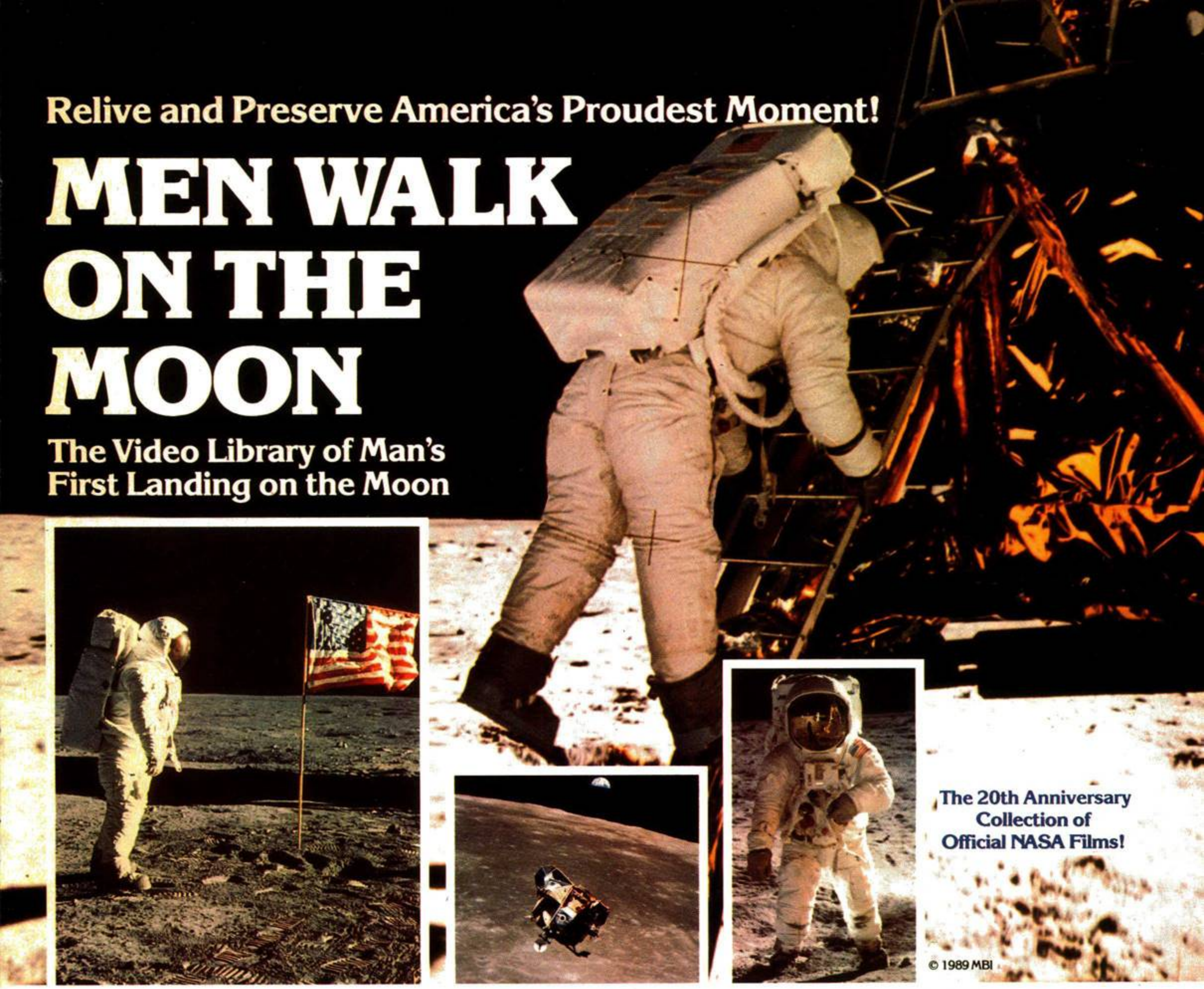

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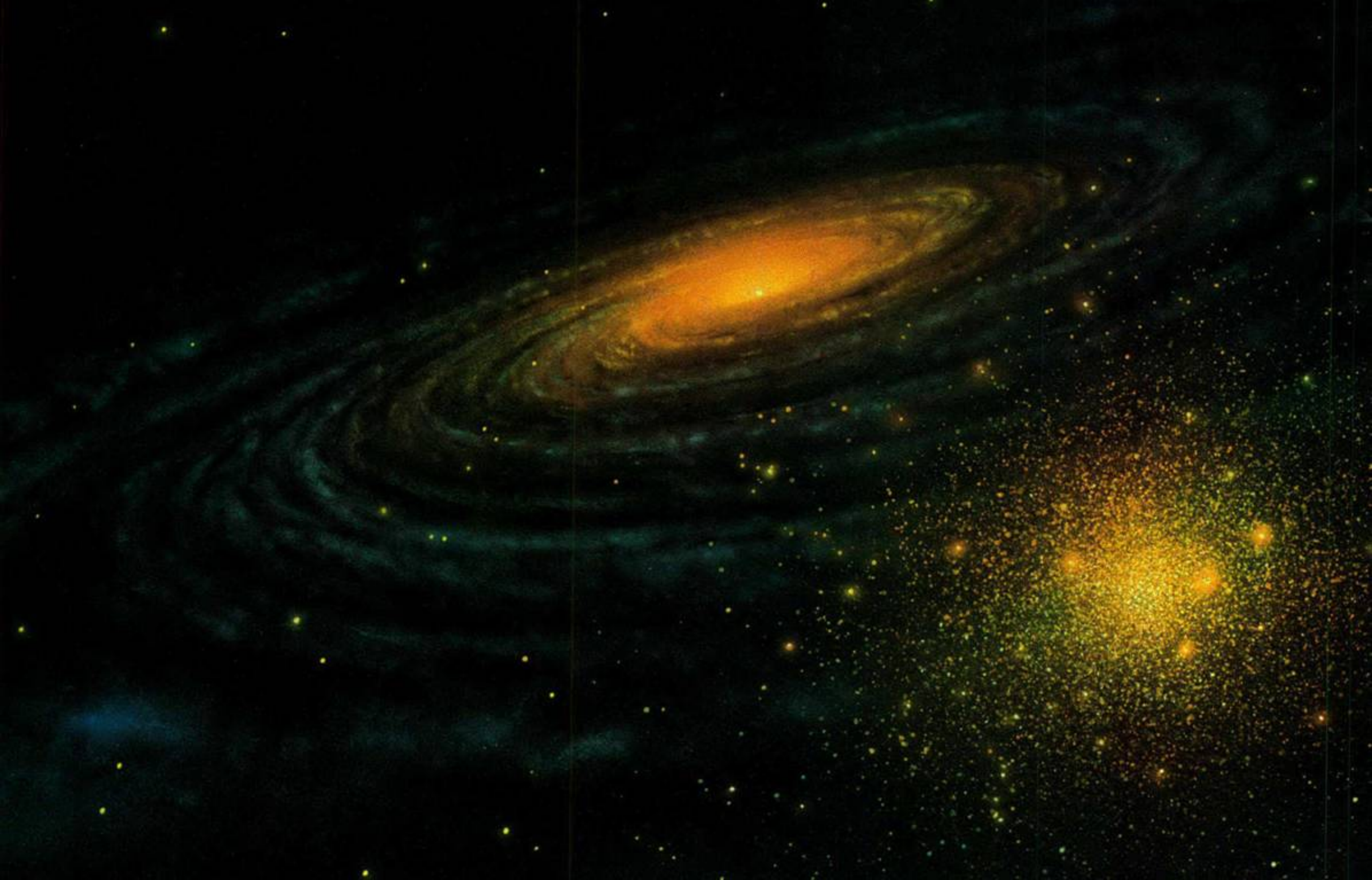
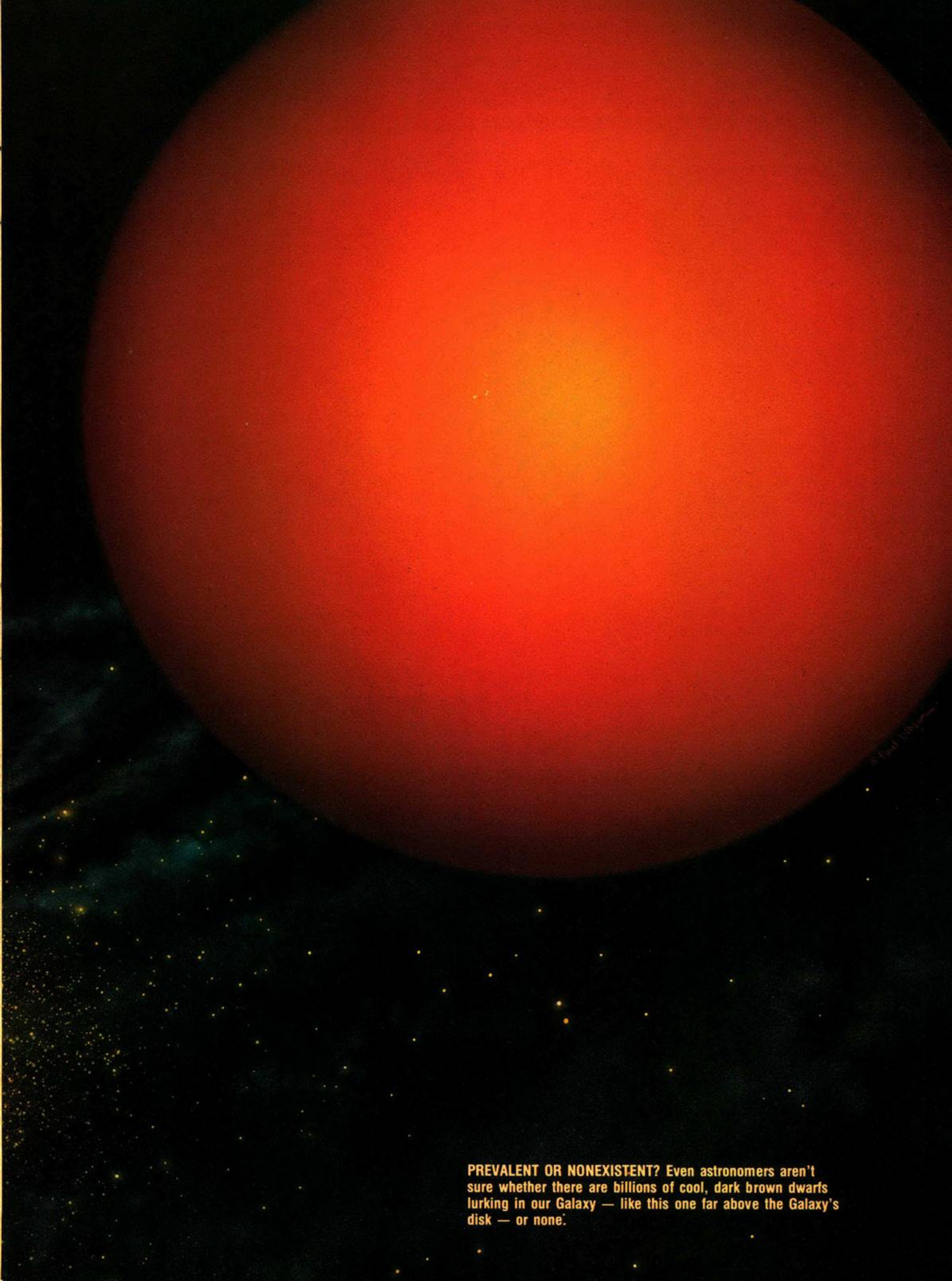
STELLAR ASTRONOMY

Do Brown Dwarfs Really Exist?

The search is on for brown dwarfs — bigger than a planet, smaller than a star, and, so far, existing only in theory.

by Deborah Byrd





PREVALENT OR NONEXISTENT? Even astronomers aren't sure whether there are billions of cool, dark brown dwarfs lurking in our Galaxy — like this one far above the Galaxy's disk — or none.

Some astronomical objects exist in the minds of astronomers before they are discovered in the real universe. Neutron stars, for instance, were postulated in the 1930s, long before pulsars were discovered and found to be neutron stars in the late 1960s. Similarly the existence of the cosmic microwave background radiation that permeates space was predicted some fifteen years before Bell Laboratories researchers Arno Penzias and Robert Wilson discovered this relic of the Big Bang explosion.

On the other hand, some objects start out theoretical and stay that way. Observers may search, but evidence confirming the existence of the proposed objects remains elusive. Eventually theorists have to explain why the objects *don't* exist.

Brown dwarfs fall into one of these categories. But the question facing astronomers today is which one. Although brown dwarfs have a firm place in astronomical theory and astronomers have identified a number of promising candidates, no one is certain that brown dwarfs actually exist.

Not Quite a Star

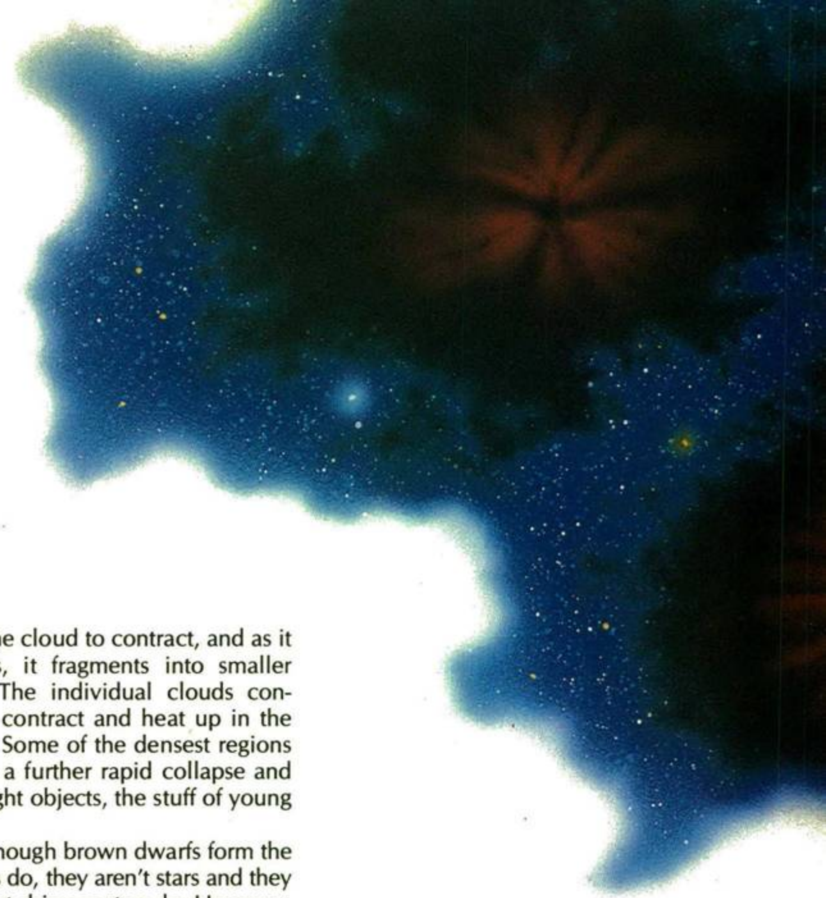
Brown dwarfs are objects that form in the same way stars do but do not possess enough mass to become stars. They are not considered stars because they never become hot enough inside to trigger hydrogen fusion, the process by which all stars shine during most of their lives. For this reason people occasionally refer to brown dwarfs as "failed stars."

The dividing line between a star and a brown dwarf — the mass above which a gaseous sphere is able to generate enough internal heat to initiate fusion — is approximately 8 percent the mass of the Sun, or some eighty times the mass of Jupiter.

There are two compelling reasons to believe brown dwarfs exist. First, a strong case for brown dwarfs can be made on statistical grounds. Second, theories that describe how stars form predict that objects smaller than the smallest stars could exist.

Astronomers observe relatively few of the most massive and intrinsically luminous stars, more stars of medium size and brightness, and a huge number of small, dim stars. Following this trend, it makes sense that there might be an absolutely enormous number of objects that form as stars do but that are even less massive than the least-massive stars.

Like a star, a brown dwarf is thought to begin its life in a giant molecular cloud. Some outside force, such as the shock wave of a nearby supernova explosion, perturbs the cloud. This causes the cloud to contract, and as it contracts, it fragments into smaller clouds. The individual clouds continue to contract and heat up in the process. Some of the densest regions undergo a further rapid collapse and form bright objects, the stuff of young stars.



Even though brown dwarfs form the way stars do, they aren't stars and they would not shine as stars do. However, they would still emit some radiation. Most of this would be infrared radiation — heat — generated by the process of gravitational contraction as the brown dwarf forms. But being close to one would be like standing next to a blast furnace: The light would be less noticeable than the heat.

For the sake of argument, suppose a brown dwarf forms with fifty times the mass of the planet Jupiter. In that case it would never get hot enough to fuse hydrogen in its core, but it could fuse deuterium, a heavy isotope of hydrogen that contains one neutron, for a short time.

"Brown dwarfs early in their lives mimic red dwarfs," said Jonathan Lunine, a theorist who works on brown dwarfs at the Lunar and Planetary Laboratory of the University of Arizona. "They're very hot. They're somewhat thermally expanded. They have large radii," he said. "After a time, however, that's no longer the case. The deuterium burns out rather quickly. They begin to cool off and shrink."

He explained, "The cooling actually occurs fairly rapidly. From a hundred million years to a billion years the object may drop by a factor of two in effective temperature — a factor of ten or more in luminosity. So it goes from being a 2500-kelvin object to a 1500-kelvin object. It begins to drop below what we think of as being easily detectable.

"And as it does so," he continued, "it shrinks somewhat in size. By the time it gets to about a billion years in age, it has reached pretty much its final size, namely, about the size of Jupiter."

From then on, he added, "things are pretty boring. The object continues to cool. It will stay the size of Jupiter, and it'll just continue to get dimmer. By the time 10 billion years have rolled around, which is roughly the age of our Galaxy, the fifty-Jupiter-mass object is going to be about 500 or 600 kelvins. Quite a bit warmer than Jupiter but much too cool to be detected from Earth."

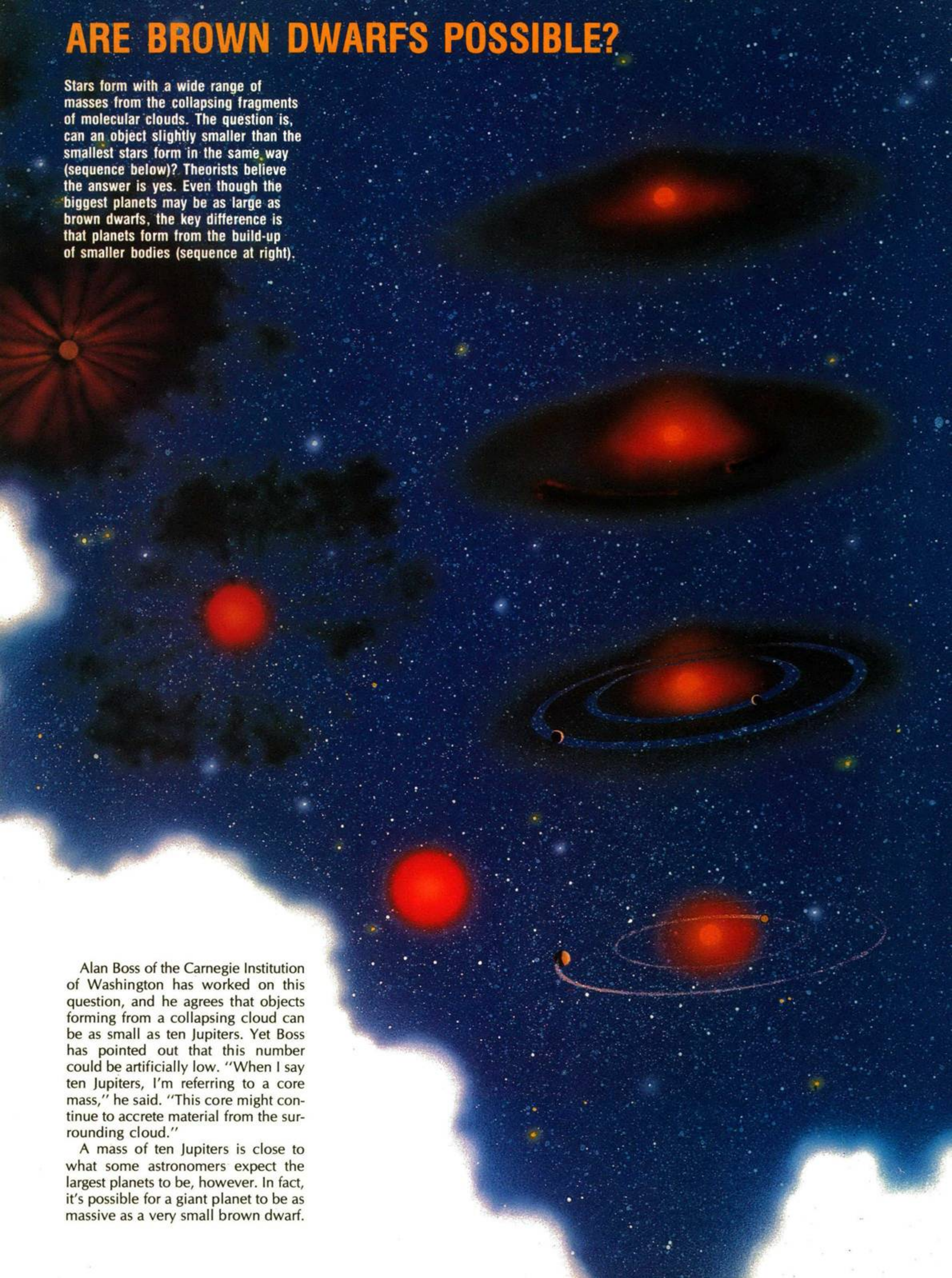
This possibility that large numbers of brown dwarfs reside in our Galaxy makes these objects attractive to astronomers for another reason: They could play a significant role in the Galaxy's "missing mass" problem. Observations of stellar motions imply that the Milky Way contains more mass than astronomers see in all the stars, gas, and dust in our Galaxy. But if brown dwarfs are as numerous as many astronomers believe, they could account for a substantial fraction of this missing mass.

Not Quite a Planet

The objects that form out of a fragmenting cloud should have a range of masses, but there is some uncertainty as to just how small the smallest objects can be. Most astronomers believe the limit is about one tenth that of the smallest stars, or roughly ten times the mass of Jupiter.

ARE BROWN DWARFS POSSIBLE?

Stars form with a wide range of masses from the collapsing fragments of molecular clouds. The question is, can an object slightly smaller than the smallest stars form in the same way (sequence below)? Theorists believe the answer is yes. Even though the biggest planets may be as large as brown dwarfs, the key difference is that planets form from the build-up of smaller bodies (sequence at right).



Alan Boss of the Carnegie Institution of Washington has worked on this question, and he agrees that objects forming from a collapsing cloud can be as small as ten Jupiters. Yet Boss has pointed out that this number could be artificially low. "When I say ten Jupiters, I'm referring to a core mass," he said. "This core might continue to accrete material from the surrounding cloud."

A mass of ten Jupiters is close to what some astronomers expect the largest planets to be, however. In fact, it's possible for a giant planet to be as massive as a very small brown dwarf.

The distinction between the two classes of object is not based on mass but on how they form.

Brown dwarfs form from collapsing clouds of gas and dust. Planets, on the other hand, form by the accretion of smaller bodies of rock and ice. In essence, planets form by a building up process, while brown dwarfs form by a breaking down process. Unfortunately differentiating objects of the same mass solely on the basis of how they form is a problem observational astronomers have yet to solve.

This is just one reason astronomers who look for brown dwarfs often describe the search as "tricky" or "risky business." Another problem is that if they exist, brown dwarfs are too small and dim to be detected easily. All but the youngest brown dwarfs would be virtually undetectable with today's technology.

Search Problems

Particularly when they are young, brown dwarfs might appear to the eye as faint red stars. Thus, one of the principal problems in searching for brown dwarfs is differentiating them from low-mass stars. Many past and a few current brown dwarf candidates lie in the boundary region between brown dwarfs and low-mass red dwarf stars. Jesse Greenstein of Caltech phrased the problem this way: "So the question is which object that's been found is a relatively cool brown dwarf and which is a living star?"

Because the search for brown dwarfs is so difficult, the history of these objects is riddled with uncertain and even false detections. Despite the headlines and the many candidates, no object has ever been proven to be a bona fide brown dwarf. But astronomers keep searching.

Where do they look? Although there is a remote chance astronomers might stumble across an isolated brown dwarf, most searches have concentrated on looking in the vicinity of stars. A brown dwarf might turn up as a binary companion — one with a mass too low to be a star — orbiting another star.

There are several reasons for this observational bias. First, a majority of stars are found in binary systems and brown dwarfs should form the same way stars do, so there is every reason to think brown dwarfs would also form in binaries. Second, looking at stars in the hope of finding a binary system where one member is a brown dwarf gives astronomers a place to look, while an isolated brown dwarf could be anywhere.

And third, if astronomers find a brown dwarf candidate in a binary system, they can "weigh" the candidate by its gravitational effect on the companion star. In that way they can determine whether the object's mass falls in the brown dwarf range or whether it is a bit too high and thus just another low-mass star.

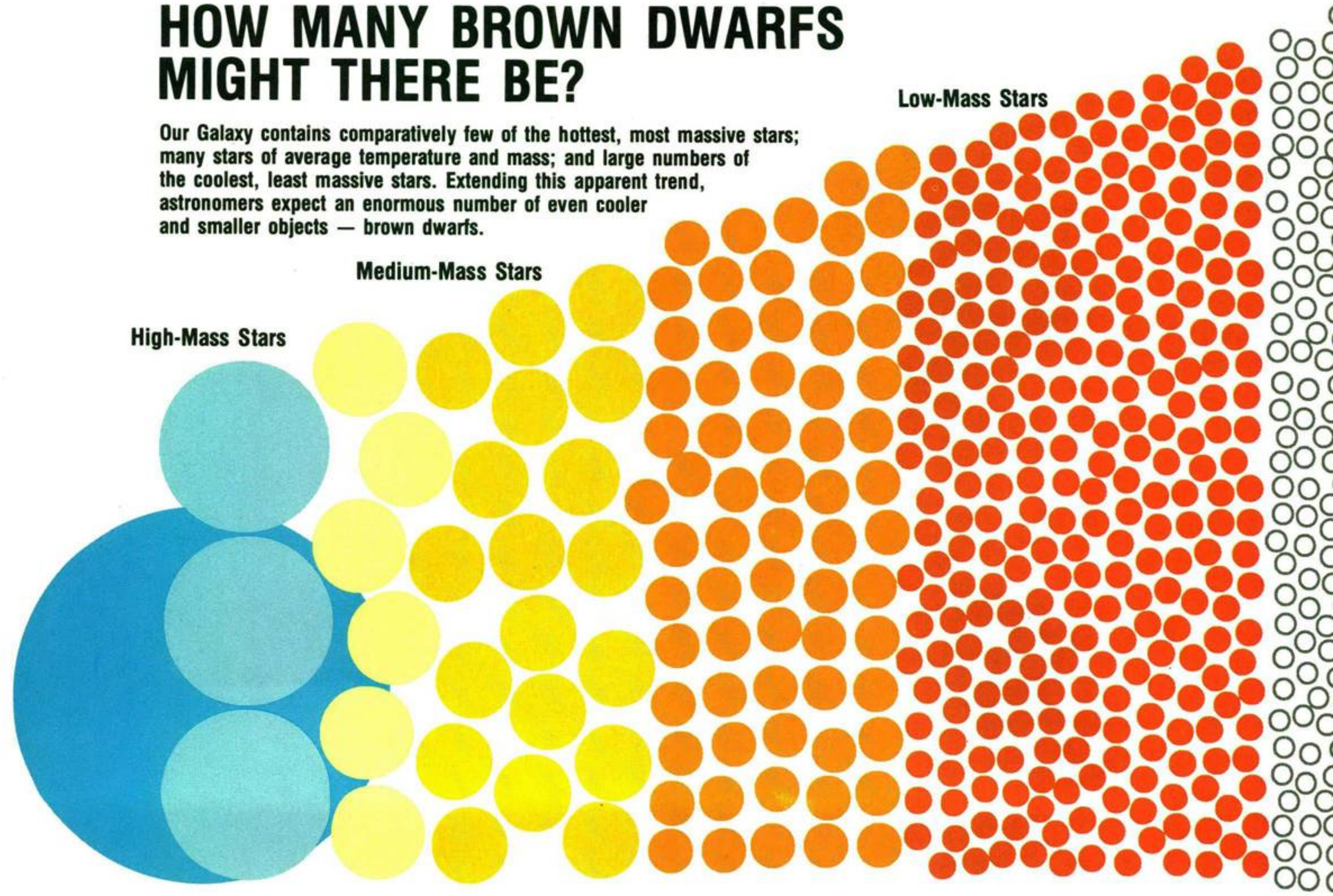
Looking for the Heat

Astronomers use a variety of search techniques in their quest for brown dwarfs with varying results. Using direct infrared imaging, William Forrest, Michael Skrutskie, and Mark Shure have been surveying faint red stars. They make their observations at one of the world's best sites for groundbased infrared observations — Mauna Kea, Hawaii — with the NASA Infrared Telescope Facility.

"Basically we point an infrared camera at the star and take a picture," Skrutskie said from his office at the University of Massachusetts. "We're looking well away from the primary

HOW MANY BROWN DWARFS MIGHT THERE BE?

Our Galaxy contains comparatively few of the hottest, most massive stars; many stars of average temperature and mass; and large numbers of the coolest, least massive stars. Extending this apparent trend, astronomers expect an enormous number of even cooler and smaller objects — brown dwarfs.

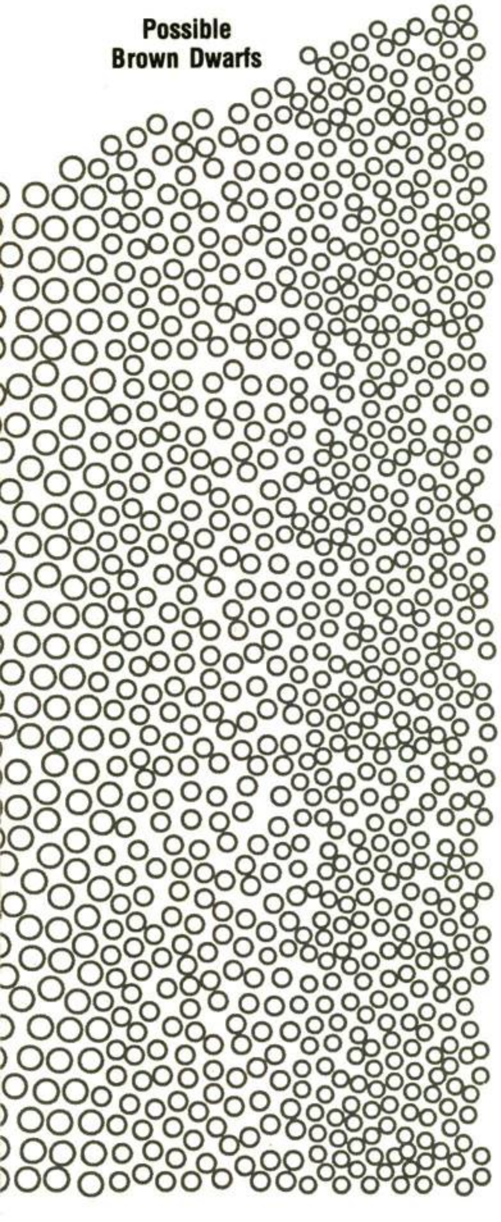


star because the light from the primary overwhelms the nearby objects."

In 1988 they announced a possible brown dwarf companion to the red star Gliese 569. The candidate object, Gliese 569B, is one of those on the borderline between stars and brown dwarfs. It is very red in color and separated from the primary star by 50 astronomical units (50 times the average distance between the Sun and Earth). Its temperature is estimated to be about 2400 kelvins.

"The minimum temperature that you would expect for a hydrogen-burning star is somewhere in the neighborhood of 2500 kelvins," Skrutskie said. But, he added, "it depends on your definition. It could be 2000 or 3000 kelvins.

"Our biggest argument for Gliese 569B being a brown dwarf is that if you compare the luminosity and temperature to other very low mass stars, it's cooler than they are. But despite being cooler, it's more luminous," he said. "When a brown dwarf is young, it's somewhat bigger than the stars and that tends to make it more luminous."



Yet Skrutskie admits it will be difficult to prove that Gliese 569B is a brown dwarf. "It's a binary companion," he said, "and if you measure the orbits of these binary stars, you can measure the masses directly. We actually have an experiment that will run, oh, somewhere between thirty and three hundred years, I guess."

"In my opinion we're not going to know in our lifetimes whether or not the thing is a brown dwarf or a low-mass star," said UCLA astronomer Ben Zuckerman, another observer actively involved in the search for brown dwarfs. "Personally I think it's just a low-mass star.

"Forrest and Skrutskie argue that because Gliese 569B is bigger than most low-mass stars, it therefore could be a brown dwarf. Well, I think the theoretical models are in bad shape. There have been so many papers published that you just can't get good enough agreement between the models and the observations to believe them at this point."

Too Much Infrared

Zuckerman and Eric Becklin of the University of Hawaii have also been looking for binary systems containing a star and a brown dwarf using the NASA Infrared Telescope Facility. But they are surveying more highly evolved stars known as white dwarfs.

White dwarfs are collapsed stars in the later stages of stellar evolution. They are very hot but very small with temperatures of 10,000 kelvins or more and diameters about the size of Earth's. This means they are relatively faint, especially in the infrared portion of the spectrum, and thus any brown dwarf companion would be comparatively easy to detect.

Zuckerman and Becklin's technique is to look for infrared excesses in the vicinity of white dwarf stars. In other words, they search for white dwarfs emitting more infrared radiation than theory predicts they should. And they are finding them. Their most recent paper describes an apparent infrared companion to the white dwarf GD165 that is an estimated 120 AU from the primary star.

"It stands off from all the rest of the cooler stars that we've seen," Zuckerman said. "It's cleanly below them at 2100 kelvins. Depending on which theoretical models you use, it's either a brown dwarf with a mass between 6 and 8 percent that of our Sun or it's a star at the very bottom of the main sequence."

Zuckerman and Becklin say that, with one exception, GD165B is the "coolest dwarf star ever reported." The exception is a possible companion to the white dwarf Giclas 29-38, reported by them in late 1987. (See "Brown Dwarf Orbits Nearby Star," AstroNews, February 1988.) Many other astronomers call this earlier candidate of Becklin and Zuckerman "promising."

Yet it is mysterious. Unlike GD165B and Gliese 569B, no direct image exists. The primary star, Giclas 29-38, shines more brightly in the infrared than expected. The observations fit well with a possible brown dwarf companion at 1200 kelvins.

Other possible explanations for the infrared excess include a disk of dust particles in orbit around the white dwarf. The white dwarf might be heating the particles, which would cause them to radiate in the infrared. Ordinary dynamical effects would cause the dust to spiral inward rather quickly, however. It's hard to see how it would be replenished in the vicinity of such a highly evolved star as a white dwarf.

A number of astronomers have observed Giclas 29-38, but none of the results has identified the infrared excess. "There are three possibilities," said Zuckerman. "Either it's clearly a dust cloud. Or it's clearly a brown dwarf. And the third possibility is that it's still unclear. And that's the way it looks right now."

There are further complications. "The observations say that it has to be within 5 AU," said Skrutskie. "Well, before a star becomes a white dwarf, it becomes a red giant. It's conceivable that the secondary star was orbiting within the envelope of the red giant.

"We may actually be seeing an object that has been evaporated by this process. It has been made into a brown dwarf. But there's a fundamental difference between seeing a brown dwarf that is an evaporated star versus seeing one that formed as a brown dwarf.

"The really fundamental question is, in what proportion according to mass do these stars form?" he said.

Changing Speeds

A fourth possible brown dwarf was discovered last year by David Latham of the Harvard-Smithsonian Center for Astrophysics in the course of a radial velocity survey of many hundreds of stars. (See "Sunlike Star Has Planets?," AstroNews, November 1988.)

The radial velocity technique uses stellar spectra, sometimes taken over a period of years, to search for cyclic motions in a star's position. If a star has a companion, the two orbit about

WHERE DO THE BROWN DWARF CANDIDATES STAND?

		Brown Dwarf Status		
Candidate	**Location**	**Yes**	**Maybe**	**Unlikely**
Barnard's Star	Ophiuchus	☐	☐	☒
GD165B	Bootes	☐	☒	☐
Giclas 24-9	Aquila	☐	☐	☒
Giclas 29-38	Pisces	☐	☒	☐
Gliese 569B	Bootes	☐	☒	☐
Gliese 623B	Hercules	☐	☐	☒
HD 114762	Coma Berenices	☐	☒	☐
Van Biesbroeck 8B	Ophiuchus	☐	☐	☒
Wolf 359	Leo	☐	☐	☒

their common center of mass. If any of this orbital motion is along our line of sight, the lines in a spectrum of the pair would be displaced slightly. Even if the companion is too faint to be seen, the shifting spectral lines may reveal it.

Typically the spectra of stars that are being analyzed for motion are compared to the spectra of standard stars. However, one of Latham's standard stars, HD 114762, was not well behaved. Being curious, he tried to fit an orbit to it, and an 84-day orbit fit beautifully. A group of astronomers in Geneva, Switzerland, later confirmed this orbit.

The calculations indicate that HD 114762's possible companion could have a mass as small as fourteen Jupiters, an orbital period much like that of Mercury, and it goes around a star so much like the Sun that it's "almost scary," according to Latham.

On the other hand, the mass of the companion could be as large as a few hundred Jupiters, which would make the companion a star — and not even one of the least-massive ones. "If it were a very unusual case of the orbit being exactly aligned in the plane of the sky, the radial velocity could be very small for that reason, not because of a low-mass companion," he said.

Other astronomers are quick to agree.

"It depends on the geometry of the system," said Michael Skrutskie.

Ben Zuckerman added, "Latham and his collaborators have looked at hundreds, maybe thousands of stars over the last few years. And if you look at thousands of stars, you're going to find one every now and then that has an inclination nearly in the plane of the sky."

Meanwhile Latham has a stack of hundreds of newspaper and magazine clippings that appeared after his announcement of HD 114762 at last summer's meeting of the International Astronomical Union in Baltimore. "The lurid headlines all say 'giant planet,'" he said.

Most of these astronomers claim they are not looking for planets. Instead their search for brown dwarfs stems from the "missing mass" question. Might there be enough brown dwarfs to account for the mass needed to explain the motions of stars in our Galaxy? Yes, if they exist.

But some astronomers are beginning to doubt that they do. "The nondetections are overwhelming," said Geoffrey Marcy of San Francisco State University.

Marcy and a few other astronomers *are* searching for planets in orbit around distant stars. They are using a technique pioneered by Bruce Campbell of the University of Victoria in British Columbia, which yields highly sensitive radial velocity measurements of relatively bright, nearby stars. (See "Possible Planetary Systems Discovered" by Richard Talcott, September 1987.)

Campbell now has a list of half a dozen or more stars that show evidence of having companions in the mass range of one to ten Jupiters. Meanwhile his technique reveals absolutely no evidence for brown dwarfs.

"I think that my work, for example, and Campbell's work show conclusively that brown dwarfs as companions to stars cannot constitute a significant fraction of the missing mass," said Marcy. "It's possible that field brown dwarfs, those just floating around by themselves, may still be part of the missing mass.

"If I may say so, there's been almost a coverup in astronomy. I hate to use such a strong word, but there have been decades of astrometric work, people looking for literal wiggles of stars in the sky. All the stars in the solar neighborhood — hundreds of stars within 10 to 20 parsecs — have been surveyed for proper motion and parallax and so forth. If a wiggle existed, it would have been detected," he said, adding that a combination of past surveys, with the resulting very long baseline, would yield a detection limit of about ten Jupiters.

"I feel for a guy like Jonathan Lunine," Marcy continued. "Here's somebody who really does excellent theoretical work on brown dwarfs, and there's a growing suspicion in my mind at least that brown dwarfs don't form at all."

"He's become a nonbeliever, that's right, by his survey," said Lunine. "One wants to wriggle out of that interpretation. One possibility is that Marcy just hasn't observed long enough, that most of these objects have reasonably long periods so you'd have to observe over many years to see the periodicities. But that's a mystery, and it's worrisome."

He continued, "To some extent I think that there are observational selection effects involved. The general feeling is that binary star systems like to form stars that are of similar mass. That's true theoretically and to some extent it's true observationally. You don't find a large population of binaries in which you have a G- and an M-type star. Where you see a lot of M dwarf binary systems, you see two M dwarfs.

"We're just at the threshold," Lunine said. "And when technology is at the threshold of finding things, these things are very rare. But once you get the technology to go well below the threshold, then you begin to find them." ☐

Deborah Byrd is the creator, writer, and producer of the daily radio series "Star Date." She also writes the monthly Eye on the Sky column for ASTRONOMY's Sky Almanac.

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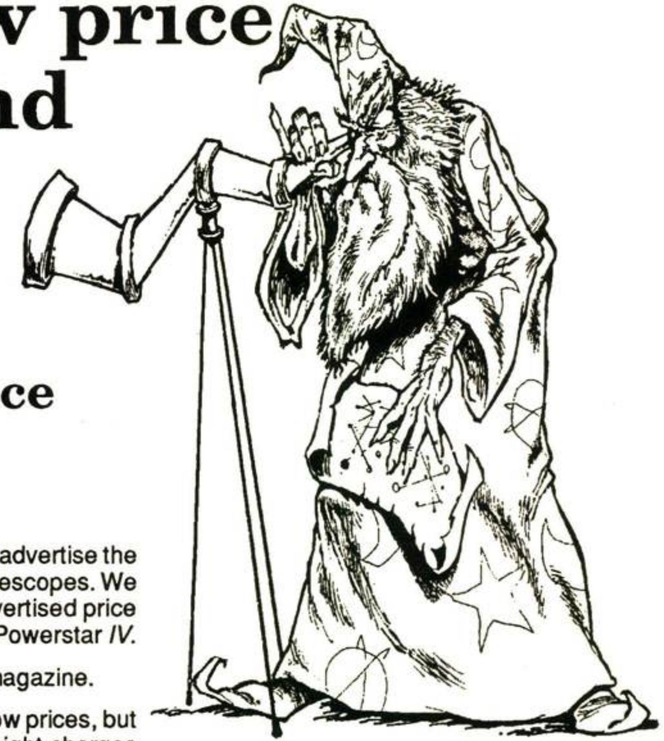

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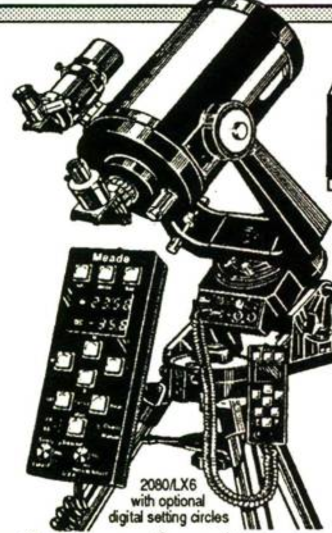

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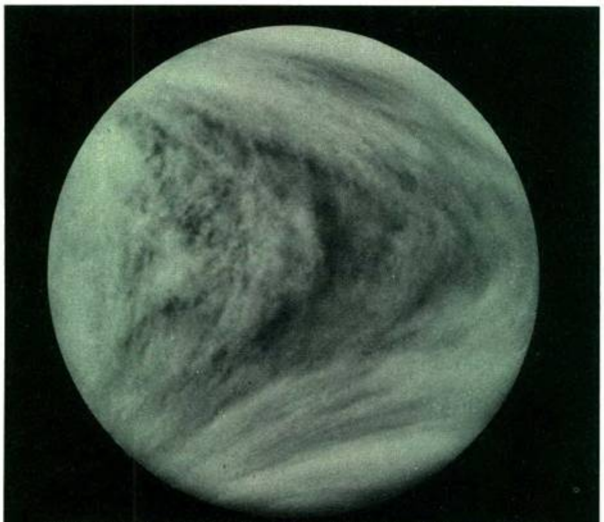
Venus Unveiled

Piercing Venus' cloud cover with radar, *Magellan* will produce the most detailed map yet of the planet's mountains and valleys.

by Stephen D. Wall

Mapping Venus is like wrapping a spaghetti noodle around a large beach ball two thousand times." That's how planetary scientist Mike Kobrick sees the *Magellan* mission to Venus, which is due for launch from the space shuttle this month. *Magellan*'s goal is to provide us with the first global view of Venus that is detailed enough to reveal the planet's geological features. Kobrick wants to see Venus in global perspective because it comes closer to Earth than any other planet, both in distance and physical characteristics.



SWIRLING CLOUDS hide Venus' surface from sight, so *Magellan* will map the planet by radar.

Why study Venus? Planetary scientists have learned that planets are wondrously complex machines, but investigating any one in isolation is fruitless. Earth has been studied for as long as there have been curious people here, yet we still don't fully understand how this machine responds when we change it. That is partly because, until recently, we have been unable to see Earth as a planet. After all, it has been only four hundred-odd years since Ferdinand Magellan demonstrated that Earth was round.

Scientific investigations of other planets can be broken into three phases. The first is reconnaissance, where we take our first look at the planet as a whole. Next follows exploration, when we image the surface with enough clarity to identify its major valleys, volcanoes, and other geological features. The third phase, diagnosis, involves studying samples from the planet to determine the nature and causes of the phenomena.

The reconnaissance stage for Venus began when *Pioneer Venus* arrived there in 1978; the spacecraft used a radar altimeter to draw a general topographic map, which was finished by 1980. The map has enough detail for us to identify the major features (see opposite page), but it shows Venus only about as well as a desk-top physical globe shows Earth.

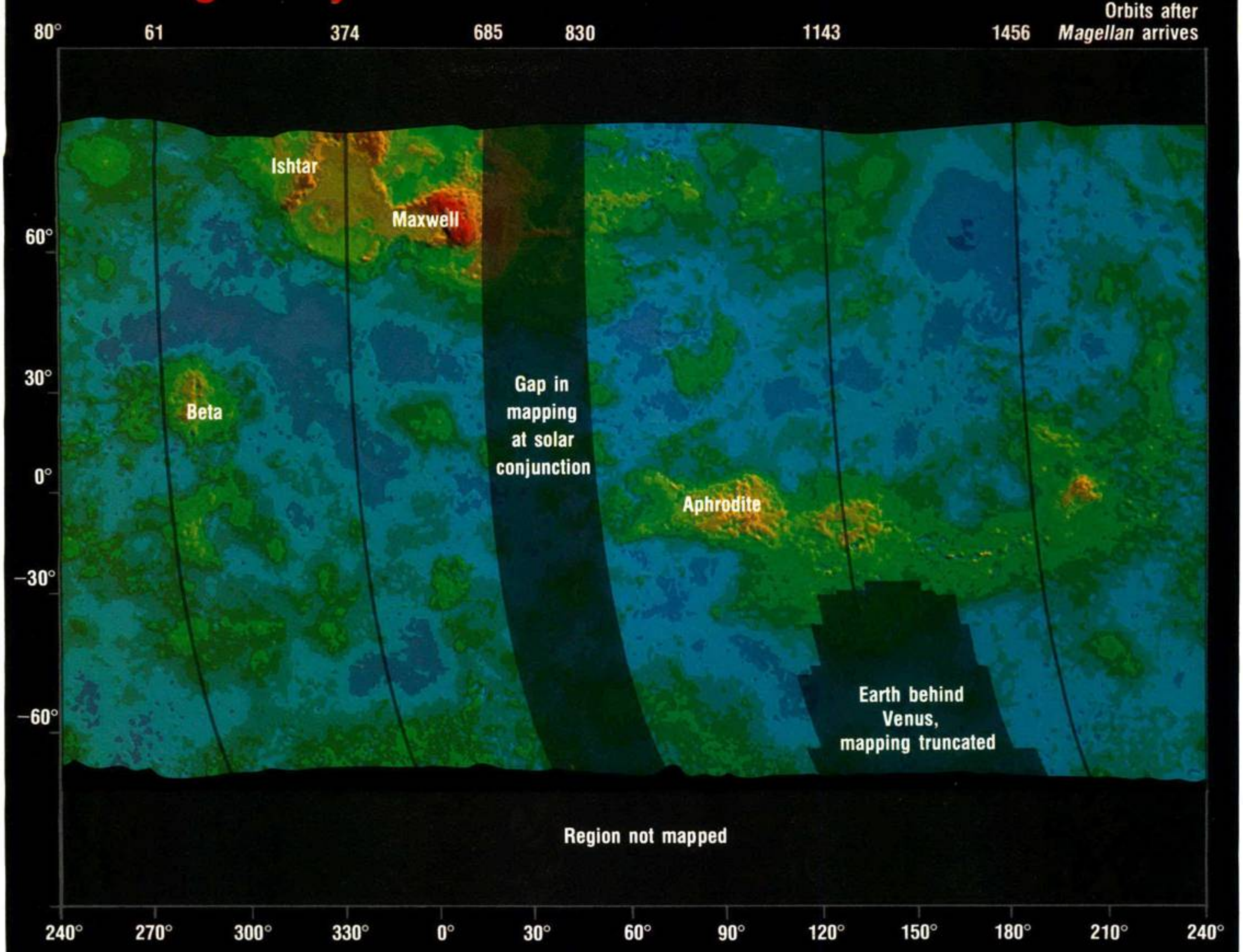
Magellan will advance our knowledge of Venus because it will take pictures over at least 70 percent of the surface with enough resolution to identify objects as small as half a mile across. This represents about a hundredfold improvement over *Pioneer Venus* and is detailed enough to reveal features the size of volcanic cinder cones, craters, faults, and landslides. *Magellan*'s altimeter will measure Venus' topography and a radiometer will record the planet's natural radiation of microwaves. In a separate experiment scientists will track the satellite carefully and use deviations in its orbit to locate regions where Venusian gravity is stronger or weaker. This will provide information about the planet's interior.

Again, why do we care? Why is there more than just academic interest in a planet we will never set foot upon, let alone try to populate?

There are two answers. First, there is a basic human desire to know. Curiosity alone is enough justification for many people. That desire has now led us to examine not only our immediate environment but also the neighboring planets and other objects in the sky. "Venus is the only terrestrial planet whose geological character is unknown," said *Magellan* project scientist Steve Saunders. "Existing imagery plus topographic and gravity data are tantalizing and suggestive, but they lack enough resolution to decide questions like where the major features come from."

Second, Venus also offers us possible solutions to one of our "at home" needs: learning how a planet works. And to understand a system as complex as a planet, you need more than one example. This is becoming very important as Earth has begun to show the effects of our presence, and some effects are not good.

Peeling away the Venusian Clouds



As Venus slowly rotates under the orbiting spacecraft, *Magellan* will redraw most of the planet's map, building up a detailed radar image during roughly two thousand orbits. Background: The base map of Venus, compiled by *Pioneer Venus* a decade ago, shows only the planet's largest-scale features.

Air pollution, waste mismanagement, and deforestation are a few ways we are threatening our own future.

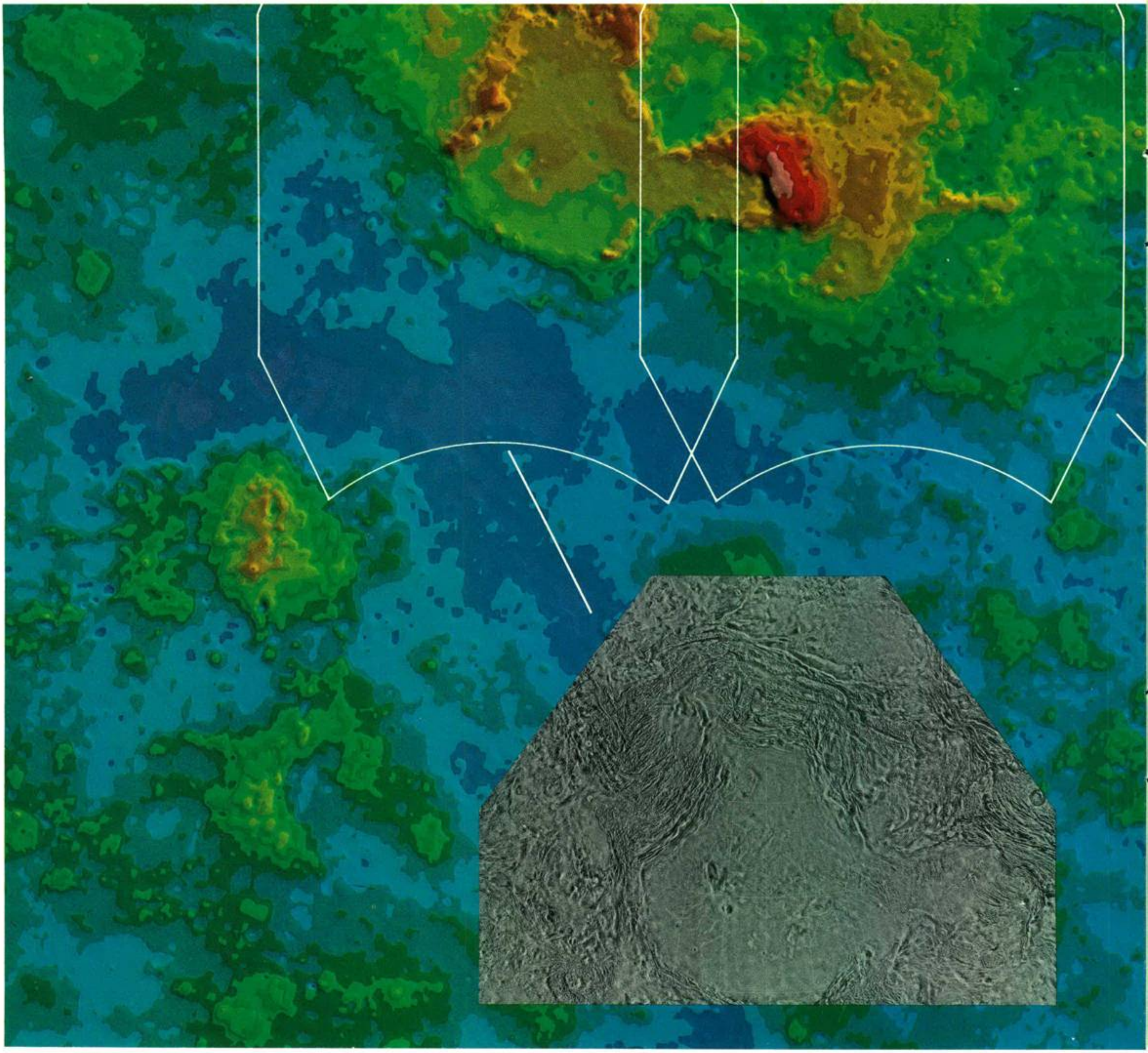
By understanding Earth and its neighboring planets better, scientists can create a model planet in a computer. By then asking the model "what if" questions, we can explore, for example, what might happen if we continue to dump more carbon dioxide into our atmosphere. We have probably already warmed the atmosphere by increasing its carbon dioxide content, and if the trend isn't halted soon, we are facing perhaps the greatest threat to Earth's future.

Our first looks at Venus showed major similarities to Earth — size, mass, bulk composition, and distance from the Sun. However, closer examination has revealed major differences. Venus' surface temperature reaches over 900° F, and its atmosphere (mostly carbon dioxide) is ninety times as thick as ours. It has thick clouds opaque to visible light and exhibits a greenhouse effect that went totally out of control. What sent these two "sisters," so similar in origin, down such divergent paths?

The Long Birth of *Magellan*

Astronomers long ago discovered that Venus has an atmosphere that completely blocks any view of the surface at visible wavelengths. Radar, with wavelengths that can penetrate the thick clouds to reach the ground, was first used to measure Venus' 243-day retrograde rotation in the 1960s. But while they could pierce the cloud veils, Earth-based radars lacked the precision necessary to depict the real face of Venus.

In 1970 the National Academy of Sciences proposed sending two satellite missions to Venus to map its surface using radar from orbit. NASA's Ames Research Center then commissioned a study that recommended a technique called synthetic aperture radar (SAR for short) that had previously been used only in aircraft. Three missions resulted from that study: *Pioneer Venus*, an oceanographic Earth satellite called *Seasat*, and *VOIR*, which is the French verb "to see" and also an acronym



for *Venus Orbiting Imaging Radar*. The story of today's *Magellan* mission begins here.

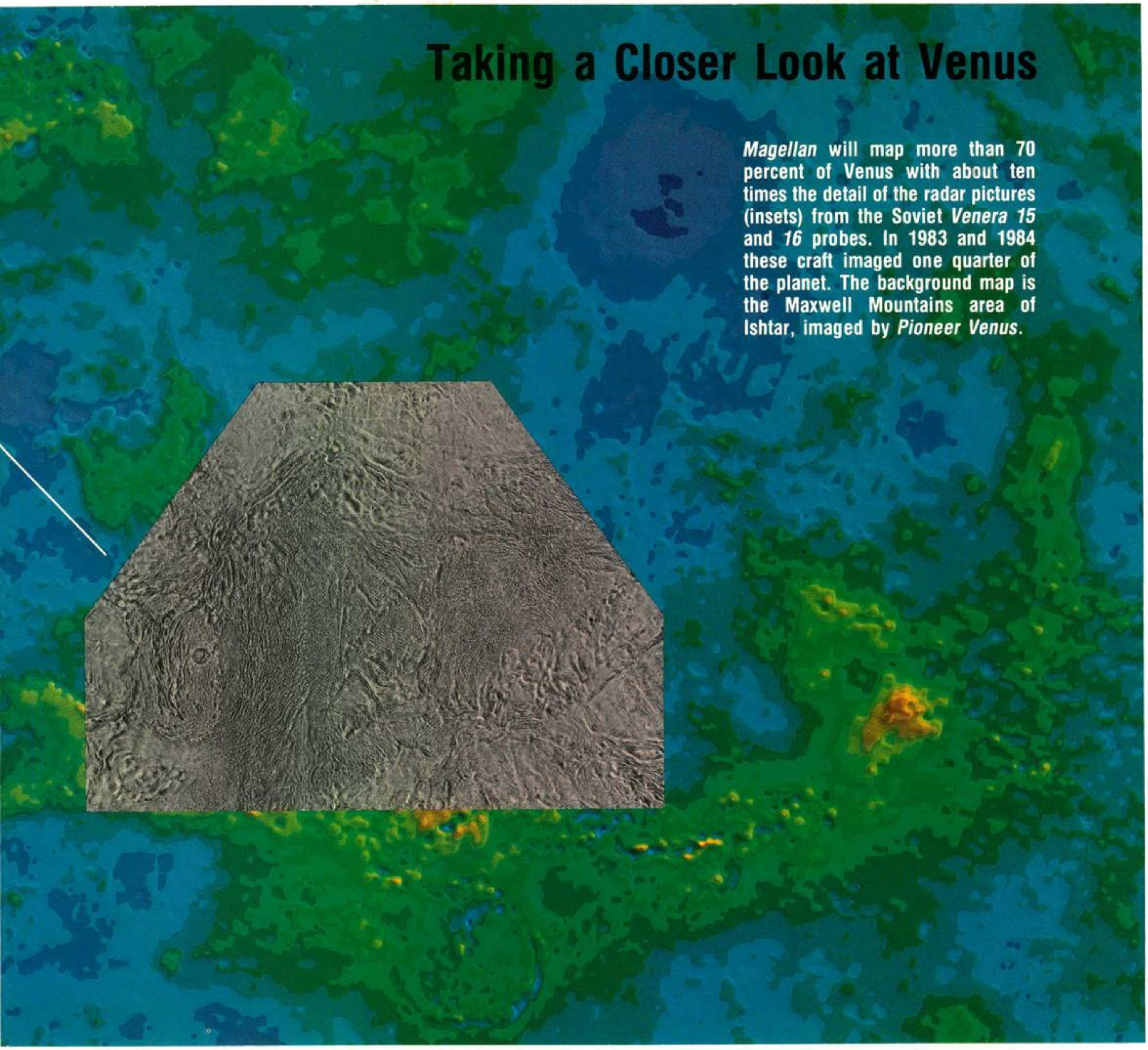
Through the 1970s studies examined the feasibility of sending a SAR to Venus to follow *Pioneer*. In 1970 Gordon Pettengill of MIT chaired a science working group to develop a plan for *VOIR*. By 1979 a team of scientists had been chosen, and in 1980 NASA granted the project a new start under the management of Caltech's Jet Propulsion Laboratory (JPL). Launch was aimed for 1983.

In early 1981, however, the newly elected Reagan administration, which at first had been positive toward *VOIR*, abruptly canceled the project. Says Pettengill, "They figured they didn't have the money." A year later a slightly scaled-down version was also rejected, and scientists and engineers realized that the mission needed a major rethink if its costs were to be acceptable.

Mission planners calculated that money could be saved if *VOIR*'s custom-made computer was dropped and a spare from the *Galileo* mission to Jupiter was substituted. If an elliptical orbit (compared to *VOIR*'s circular one) would suffice, an off-the-shelf solid rocket could replace the custom-made liquid-fuel engine used to put the craft in Venus orbit. SAR engineer W. T. K. Johnson then modified the radar to work in such an orbit. He saved additional funds by stealing a spare antenna from the *Voyager* mission (by this time on its way to Saturn) and made it do double duty as the antenna *Magellan* would use to communicate with Earth. But *Voyager*'s antenna had the wrong shape, which put additional requirements on the SAR, and these were in turn offset by deleting the SAR computer and giving the work to the more intelligent *Galileo* computer. "We had a smart bus [satellite]," Johnson said, "so we figured we could live with a dumb SAR."

And so it went. All atmospheric sensors were

Taking a Closer Look at Venus



Magellan will map more than 70 percent of Venus with about ten times the detail of the radar pictures (insets) from the Soviet *Venera 15* and *16* probes. In 1983 and 1984 these craft imaged one quarter of the planet. The background map is the Maxwell Mountains area of Ishtar, imaged by *Pioneer Venus*.

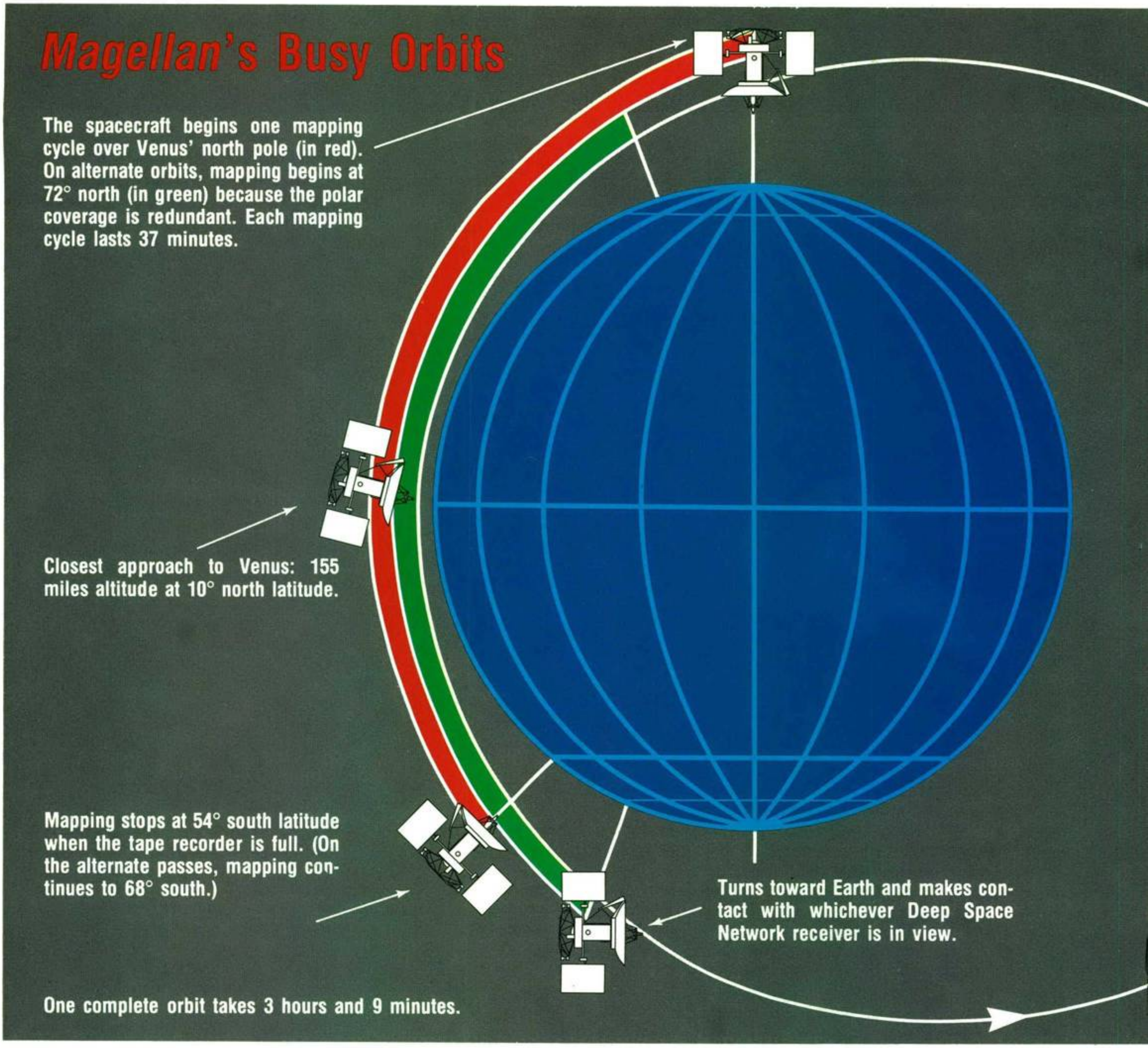
removed, as was a high-resolution SAR mode. Major cuts were made in the operations team. The result was a much more tightly focused mission, which, despite the drastic "descoping," would still produce a tremendous advance in planetary science. NASA accepted the new version and offered it a new start in 1984 as the "Venus Radar Mapper," a name soon changed to *Magellan*.

Building a Spacecraft from Spare Parts

Magellan has taken a long time — more than fifteen years — to reach the launch pad, and it is as much a marvel of low-budget engineering as it is of high technology. Earlier spacecraft (including the *VOIR* design) were largely custom-built. *Magellan*, however, is the result of many previous designs and, in some cases, uses already built hardware. In addition to the antenna, the spacecraft itself is made up of a *Voyager* "bus," or main structure, with *Voyager* propulsion components, thermal control louvers, and radio system components. *Galileo* contributed a main computer, tape recorder, attitude control processor, power subsystem, and more. Other donors include the shuttle, *Viking* Mars orbiters and landers, the Inertial Upper Stage booster, and the *Ulysses* solar mission. Only about a third of *Magellan* is custom designed.

The core structure of *Magellan* is about the size of a U-Haul moving van. Add a pair of flat, blue, solar power panels sticking out from each side and put a 12-foot dish antenna on one end and you have an idea of the size of this rather ungainly structure. Just behind the large antenna is the forward equipment module, which contains the SAR electronics and three gyroscope-like reaction wheels. When the craft must turn — for example, to scan the surface or to point the antenna toward Earth — these massive, spinning wheels are sped up. Unconstrained by gravity, the craft reacts by turning in the desired direction. *Magellan* can also reverse the

Magellan's Busy Orbits



The spacecraft begins one mapping cycle over Venus' north pole (in red). On alternate orbits, mapping begins at 72° north (in green) because the polar coverage is redundant. Each mapping cycle lasts 37 minutes.

Closest approach to Venus: 155 miles altitude at 10° north latitude.

Mapping stops at 54° south latitude when the tape recorder is full. (On the alternate passes, mapping continues to 68° south.)

Turns toward Earth and makes contact with whichever Deep Space Network receiver is in view.

One complete orbit takes 3 hours and 9 minutes.

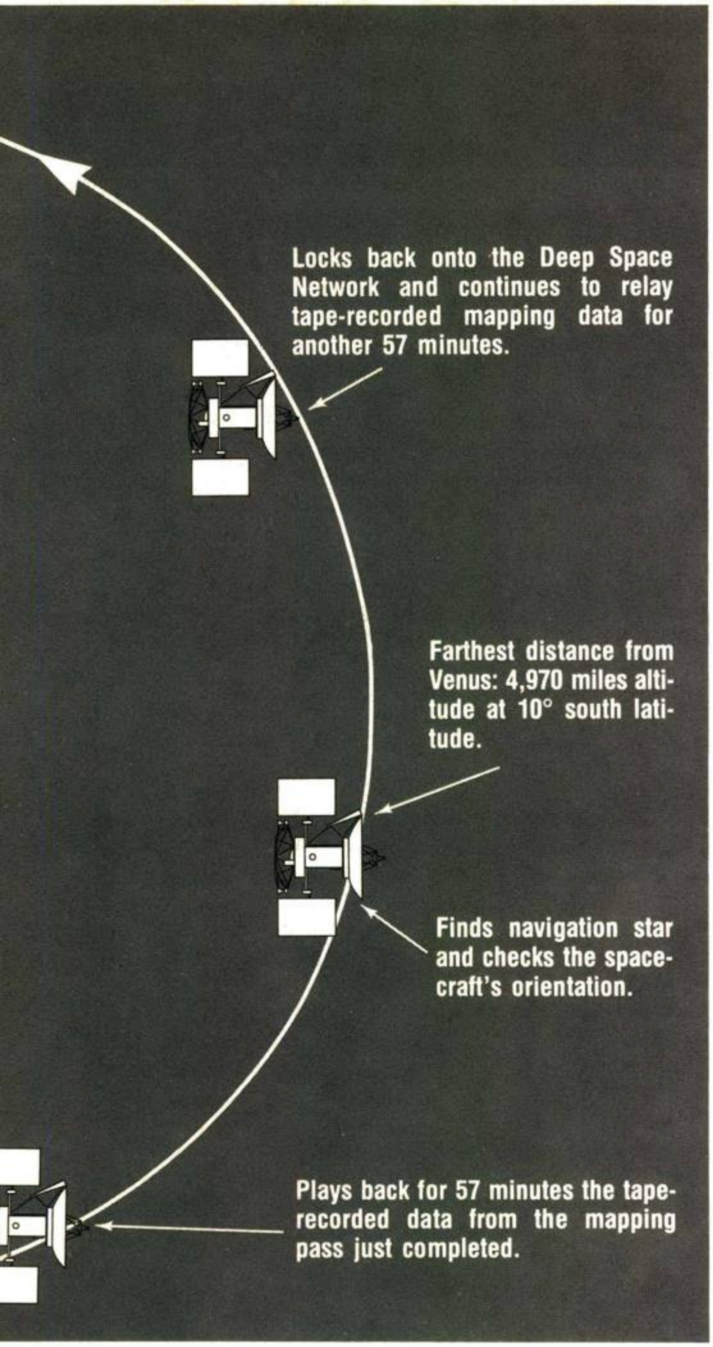
procedure and reclaim momentum when it needs to turn the other way. Only when the wheels are spinning too fast does the craft use thrusters to correct the situation.

The main bus behind the forward equipment module carries most of the electronics, and the solar panels attach here as well. A star scanner protruding from the side is used once each orbit to orient the spacecraft. Both the bus and the equipment modules produce heat, so adjustable louvers on their sides open and close to control temperatures inside. Behind the bus a spiderlike structure supports the attitude control thrusters. At the rear of the craft lies the Star-48B solid rocket, which will slow *Magellan* on arrival so it can be captured into orbit by Venus' gravity.

Mapping through the Clouds

Magellan carries only a single instrument, but this performs three separate science experiments. (A fourth experiment, mapping the planet's gravity field, uses the entire satellite as its instrument.) The multipurpose instrument collects three kinds of data — SAR, altimetry, and microwave radiometry — many times each second, using the same electronics in different ways.

First, a radar transmitter emits a series of coded microwave pulses through the main antenna and listens for the return echoes. The antenna points to the side relative to the craft's motion, and the returning echoes, sorted by frequency and time, can be reconstructed into a radar picture of the surface by computer processing on Earth. Next, the same transmitter sends pulses through the smaller horn-shaped altimeter antenna, which is aimed straight down. Both the returned pulse and the time it takes to make the round trip are recorded. The trip time measures very accurately the distance from spacecraft to planet, while the returned pulse can be combined with the SAR echo to determine the electrical properties of the surface rocks. Finally, the transmitter shuts down briefly and the receiver listens for the planet's natural radio waves so mission scientists can


Locks back onto the Deep Space Network and continues to relay tape-recorded mapping data for another 57 minutes.
Farthest distance from Venus: 4,970 miles altitude at 10° south latitude.
Finds navigation star and checks the spacecraft's orientation.
Plays back for 57 minutes the tape-recorded data from the mapping pass just completed.

study the thermal properties of the surface.

These three experiments yield three distinct pieces of information, in the form of images, planetary shape, and temperature. They also contain certain information in common, because they all involve the interaction of microwaves with the surface of Venus. It will be the task of the Surface Electrical Properties Working Group, headed by Len Tyler of Stanford University, to develop a computer model for the surface that fits all three of these pieces of data.

To understand how this will be done, consider the way you interpret the light reflected from everyday objects. You can tell not only what color the object is but also whether it is rough or smooth: a red cloth looks different than a red car, even when both are the same color. Just as scientists familiar with the interaction of light and matter can estimate what planetary surfaces are made of by the way light reflects from them, so will *Magellan*'s scientists use both reflected and natural microwave radiation from Venus to learn about the roughness and the electromagnetic properties of the surface. With this information in hand, together with photos of the surface taken by Soviet *Venera* landers and the SAR images from *Magellan*, planetary geologists can start to explore what kinds of rocks make up the surface.

Going the Long Way Around

Getting *Magellan* from the Kennedy Space Center into orbit around Venus calls for balancing science objectives against engineering feasibility. "It's very challenging," says veteran mission designer Sam Dallas of JPL. "This project has a more active spacecraft than most — it has to make a lot of turns to do its job. Moreover, we must track it very exactly, since we use its position to assemble the SAR map."

The hardware required on board, constraints on arrival dates, SAR requirements for orbit period, and many other factors limit the choice of launch date and vehicle. Positions of the Sun and Earth during the mission are also important, because Venus can block either the telemetry path on which the science data returns to Earth or the Sun's light, needed to power the spacecraft.

Magellan's launch window opens April 28 and closes May 27. During that time the shuttle will lift off and go into a 180-mile-high circular orbit around Earth. Astronauts will then deploy *Magellan* and its solid rocket booster, the Inertial Upper Stage, from the payload bay. The booster will fire the craft into a trajectory that takes it sunward to the orbit of Venus, which it will intersect this October. Venus won't be there to meet it, however, so *Magellan* will coast along its trajectory, which will take it away from the Sun and back out to Earth's orbit by March 1990. It then returns to Venus' orbit by August, and this time Venus will be waiting. At last, sixteen months after launch and after one-and-a-half trips around the Sun, *Magellan* will fire its solid rocket to slow its approach and go into orbit.

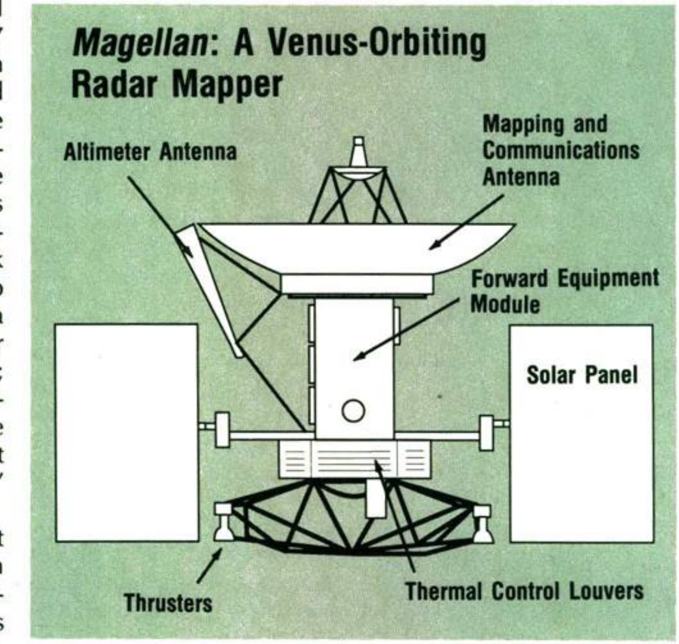
Why this lengthy route? It is a matter of delicately balancing tradeoffs. Mission planners want to take the largest possible payload using the least possible fuel. The most fuel-efficient paths follow an elliptical orbit around the Sun that reaches Venus' orbit near the planet's perihelion, or closest approach to the Sun. Such opportunities occur only every nineteen months. However, another set of opportunities opens up if we allow the craft to make one full turn around the Sun before encountering Venus.

At the end of *Magellan*'s long trajectory, all that's left is for the solid rocket engine to slow the spacecraft down so Venus' gravity can capture the craft into a highly elliptical orbit around the planet. After ground controllers carefully track the probe, they will command its hydrazine thrusters to adjust the initial orbit to one that takes 3 hours and 9 minutes. The radar will be turned on and tested and actual mapping will begin.

Wrapping the Noodle

The people who actually run the mission — the operations team — have been planning, designing, testing, and rehearsing their parts for almost as long as the project itself has been in existence. The team will track the spacecraft precisely to determine its exact orbit, use that information to tell the radar how to take data, coordinate the relaying of data to Earth, assemble the data into images, and finally analyze those images to make new scientific discoveries. With such a tiny robot so far from home, opportunities for mistakes abound. The team must watch vigilantly, making sure every error is caught before it creates a disaster.

On each successive orbit *Magellan* will image a very narrow piece of the final map — one of Kobrick's "spaghetti noodles" — a skinny sliver of data that reaches three fourths of the way from the north pole to the south. (See diagram on pages 30 and 31.) As the satellite passes over the north pole, the large dish antenna will point toward the surface and begin taking simultaneous SAR images, altimetry, and radiometry measurements.


Magellan: A Venus-Orbiting Radar Mapper

As the craft's altitude drops toward its orbital low point 155 miles above the surface, mapping will continue for about 37 minutes until enough data have been collected to fill the onboard tape recorders. Then the reaction wheels will turn the craft so its antenna points toward Earth and *Magellan* will radio data back to one of the three Deep Space Network antenna stations. Located near Barstow, California; Madrid, Spain; and Canberra, Australia, the antennas are placed so at least one can "see" Venus at any time.

When the spacecraft reaches the high point in its orbit, it ceases playback, gets a fix on its orientation with the star scanner, adjusts the spin of its reaction wheels if necessary, and then regains contact with Earth. It finishes relaying the data just in time to turn back to the planet and begin the next mapping pass.

Alternate passes will begin at 72° north latitude instead of the pole to reduce the multiply-redundant coverage in the highest latitudes. Though the strategy will be altered when either the Sun or Venus itself comes between *Magellan* and Earth — thereby preventing full playback — the same basic pattern will be followed for 243 days, until Venus has turned one full rotation beneath the orbiting craft. Careful tracking of *Magellan*'s orbit from Earth will allow ground computers to electronically knit the data noodles into mosaics that wrap around the planet.

Because of the unique nature of the radar and the cost-saving steps that have been taken, *Magellan*'s mapping of Venus will bring forth many firsts. At the top of the list is a new navigation technique borrowed from radio astronomy called very long baseline interferometry. This lets mission controllers know to high precision where *Magellan* is by comparing the signals received at any two Deep Space Network antennas with the signals received from quasars with well-known celestial positions. Scientists need extremely good navigation information to point the radar accurately and to mosaic the image strips into a map.

Pushing the Limits

If things go well, the mission will continue to run as long as there are worthwhile things to be learned about Venus. The first "cycle," or 243-day rotation of Venus, is dedicated to mapping the planet. If substantial gaps remain in the map afterward because of telemetry failures or other problems, mapping will continue. But after the basic map is complete, mission controllers will loosen the rules a little and see what more innovative remote-sensing techniques can show us about specific places. According to *Magellan* support scientist Ann Tavormina, who plans these so-called extended-mission objectives, "It'll be time to get creative — a lot more interesting."

Highest priority will go to examining the southern polar area, which must be left out of the first-cycle map. And dramatic as the pictorial data promise to be, the gravitation experiment will want its time too. The highest-precision gravity data need a strong continuing signal. To do this, the large antenna will be pointed straight at Earth while the radar beams its full mapping-strength signal, which rules out picture taking.

After the gravity survey, planetary geologists will surely have a list of places that deserve a second look. The way that the radar brightness of the surface changes with the viewing angle can reveal details about Venus' fine structure, so *Magellan* will reimage some areas at several angles. This procedure can also create stereoscopic images of interesting land features, which geologists can then view in three dimensions. Or mission scientists may wish to rotate the spacecraft and see how images of the surface change as the radar polarization changes. The large antenna could also be pointed directly down at the planet and used as a high-resolution altimeter. There is no lack of ideas as long as the little robot's health holds out.

Closing the Circle to Begin Again

August 1988 marked the tenth anniversary of the launch of the *Pioneer Venus* probe. The United States has not launched a planetary probe since then — to Venus or to any other planet. The primary scientific lesson we have learned during this decade is that understanding how planets tick is no longer just interesting. It is imperative. We are now ready to begin again, and how appropriate it is that the *Magellan* project should pick us up where we last left off — with a mission to our sunward neighbor. □

Stephen D. Wall is currently the experiment representative at JPL for the Magellan *project, where he acts as liaison between the project staff and the scientific experimenters on the mission. He joined JPL's radar science group in 1978, where he worked with* Seasat *and the Shuttle Imaging Radar projects before* Magellan.

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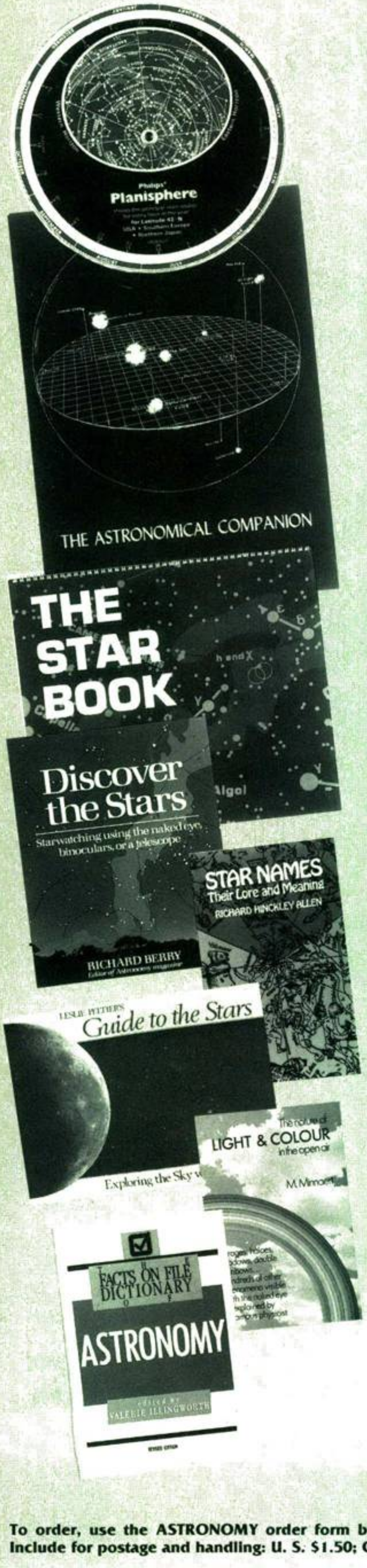

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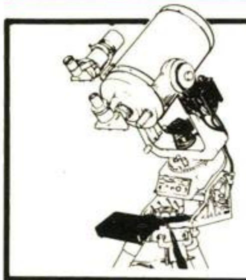

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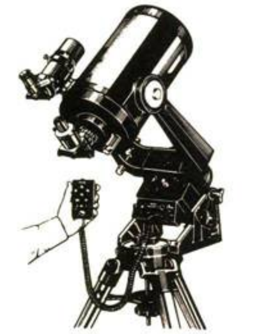

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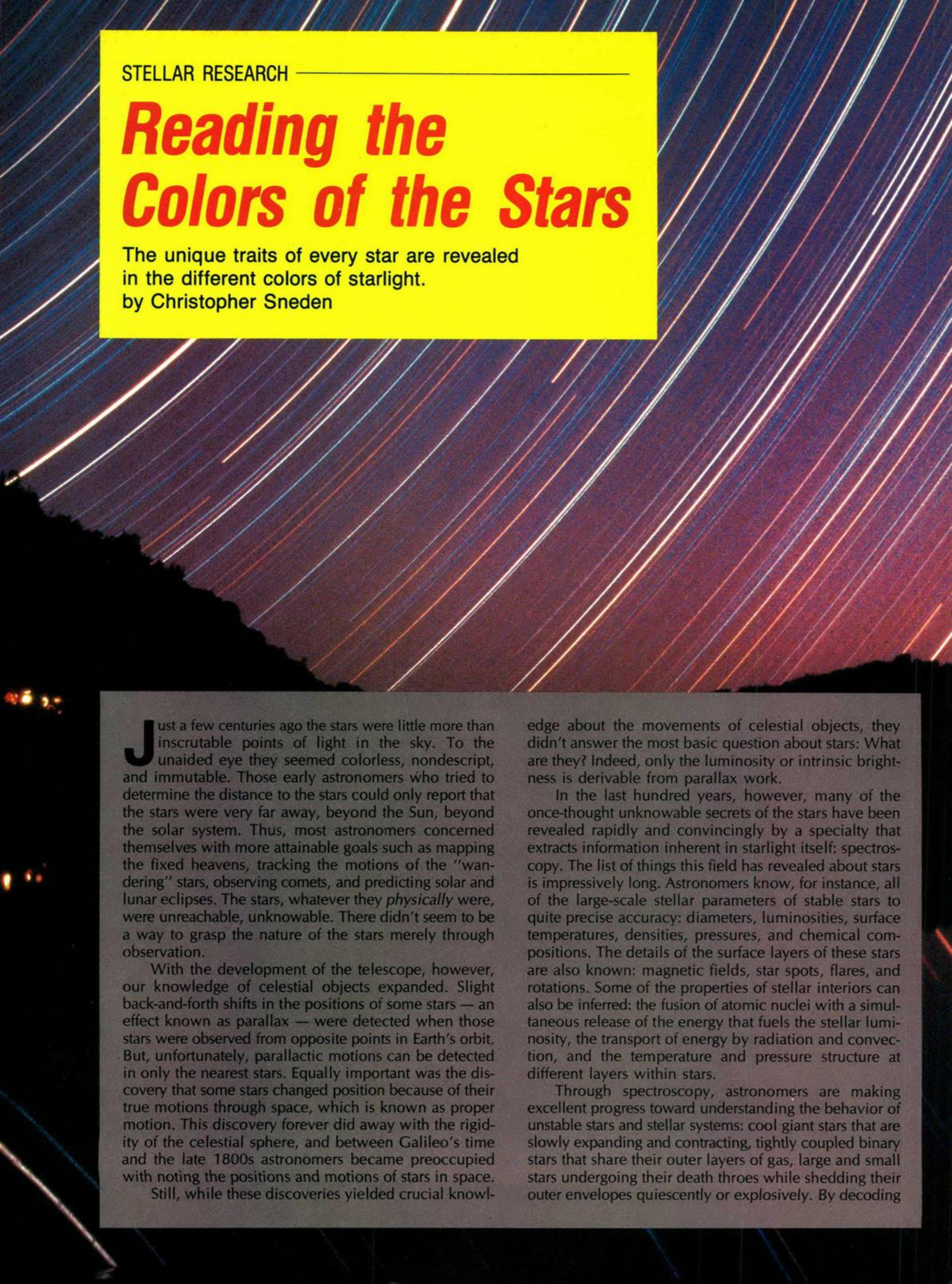


STELLAR RESEARCH

Reading the Colors of the Stars

The unique traits of every star are revealed in the different colors of starlight.

by Christopher Sneden

Just a few centuries ago the stars were little more than inscrutable points of light in the sky. To the unaided eye they seemed colorless, nondescript, and immutable. Those early astronomers who tried to determine the distance to the stars could only report that the stars were very far away, beyond the Sun, beyond the solar system. Thus, most astronomers concerned themselves with more attainable goals such as mapping the fixed heavens, tracking the motions of the "wandering" stars, observing comets, and predicting solar and lunar eclipses. The stars, whatever they *physically* were, were unreachable, unknowable. There didn't seem to be a way to grasp the nature of the stars merely through observation.

With the development of the telescope, however, our knowledge of celestial objects expanded. Slight back-and-forth shifts in the positions of some stars — an effect known as parallax — were detected when those stars were observed from opposite points in Earth's orbit. But, unfortunately, parallactic motions can be detected in only the nearest stars. Equally important was the discovery that some stars changed position because of their true motions through space, which is known as proper motion. This discovery forever did away with the rigidity of the celestial sphere, and between Galileo's time and the late 1800s astronomers became preoccupied with noting the positions and motions of stars in space.

Still, while these discoveries yielded crucial knowledge about the movements of celestial objects, they didn't answer the most basic question about stars: What are they? Indeed, only the luminosity or intrinsic brightness is derivable from parallax work.

In the last hundred years, however, many of the once-thought unknowable secrets of the stars have been revealed rapidly and convincingly by a specialty that extracts information inherent in starlight itself: spectroscopy. The list of things this field has revealed about stars is impressively long. Astronomers know, for instance, all of the large-scale stellar parameters of stable stars to quite precise accuracy: diameters, luminosities, surface temperatures, densities, pressures, and chemical compositions. The details of the surface layers of these stars are also known: magnetic fields, star spots, flares, and rotations. Some of the properties of stellar interiors can also be inferred: the fusion of atomic nuclei with a simultaneous release of the energy that fuels the stellar luminosity, the transport of energy by radiation and convection, and the temperature and pressure structure at different layers within stars.

Through spectroscopy, astronomers are making excellent progress toward understanding the behavior of unstable stars and stellar systems: cool giant stars that are slowly expanding and contracting, tightly coupled binary stars that share their outer layers of gas, large and small stars undergoing their death throes while shedding their outer envelopes quiescently or explosively. By decoding

the cryptic message of starlight, spectroscopy has revealed the stars as physical entities that can be measured and understood.

The Colors of the Stars

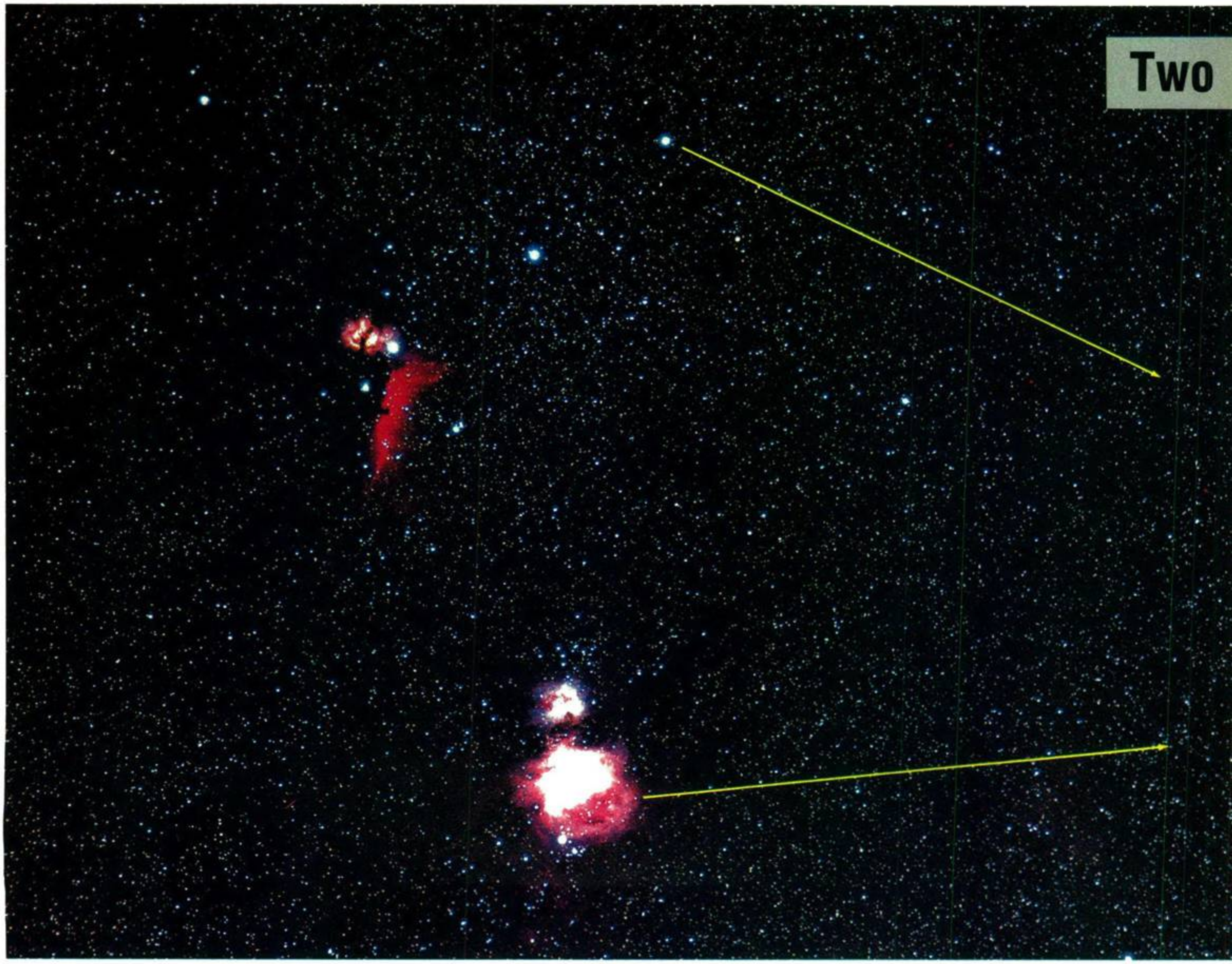
Anyone who has looked at a long-exposure color photograph of a rich field of stars has performed a simple sort of spectroscopy by noting that stars have a variety of colors, from deep red through blue.

What makes one star emit a higher percentage of red light while another emits mainly blue light? The answer is simple: Stars that appear bluish to the eye are much hotter than those that appear reddish. The blunt certainty of this statement can only be modified by the presence of dust between the observer and the star, but that effect only occurs for very distant stars and need not concern us here. Happily the justification for the temperature effects on stellar cores can be demonstrated by anyone who has access to an electric stove. As the temperature of the stove's elements increases, the elements change color, first glowing a deep red, then gradually shifting to orange, then yellow. If it were possible to increase the heat without melting the elements, eventually the elements would appear bluish. In addition to the color changes, more total energy is emitted in all colors by the elements as the temperature increases.

The colors we assign to glowing solids at different temperatures are simply the responses of the human eye and brain to the different intensities and wavelengths (or frequencies) of light. The light we see is transmitted in discrete quantities called photons, which have properties of both waves and particles. Waves have characteristic wavelengths; particles have characteristic energies. The energy carried by a photon is directly proportional to the wavelength.

Thus, within the narrow slot that makes up the part of the electromagnetic spectrum that is detectable to the eye, a beam of high-energy, short-wavelength photons is perceived as blue light, while a beam of low-energy, long-wavelength photons is perceived as red. Photons that fall between these extremes appear as green, yellow, and orange light. Higher energy emissions, such as ultraviolet light, x-rays, and gamma rays, are also part of the overall spectrum of light, as are lower-energy infrared and radio emissions.

When a solid object glows, it emits light at all wavelengths. This is why we see a rainbow of colors — a con-



tinuous spectrum — when we observe the object's light with a spectroscope. Hot objects also emit more photons at every wavelength than do cooler ones, but the peak intensity of all light occurs at progressively shorter wavelengths for hotter objects. It is a small extra step to suggest that the color of a star is a measure of its temperature.

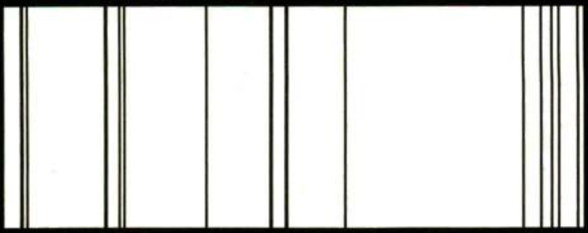
With a little more work we can use the star's temperature and its luminosity to derive its size, because as the temperature of an object is raised, the total amount of energy emitted at all wavelengths also goes up. But how do the total energy outputs of two stars with the same surface temperatures but different sizes compare? The action of our electric kitchen stove provides the answer.

Typically such stoves have four burners — two with small coils and two with large coils. Obviously you use the large coils for large pans, and that is the key. If you heat a large and a small coil to the same temperature, both will have the same color to the eye, but intuition suggests that the larger coil must be putting out more total radiation because it covers a greater area than the smaller coil.

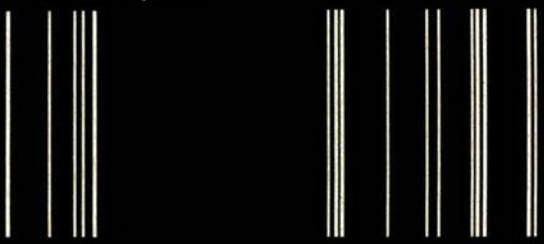
Ways to Read Starlight

The chemical content of matter reveals itself in two types of spectra. An absorption spectrum results when the atoms and molecules in the cooler atmosphere of a star selectively absorb light at certain frequencies. An emission spectrum results when ionized atoms in a nebula interact with free electrons and emit light at certain frequencies.

Absorption Spectrum



Emission Spectrum



Thus, the temperature of a glowing solid controls the color and the energy output *per unit surface area*. The total luminosity, or energy output from the whole object, is a function of both the object's temperature and its surface area. So information about the color of a well-studied star gives the temperature and energy output per unit area, while information about the star's apparent brightness and parallax gives the absolute luminosity. The mathematical combination of these two things ultimately leads to knowledge of the star's size.

By studying many stars, astronomers have discovered that the Sun's size is rather ordinary: some supergiant stars have diameters hundreds of times that of the Sun (they would swallow the inner planets if put in place of the Sun). On the other hand, some dwarf stars have diameters only slightly larger than Earth's.

Types of Spectra

If temperature, luminosity, and size were all that could be determined from stellar spectra, astronomers would still know very little about the nature of stars. Fortunately, clues to a star's structure and chemical composition can also be determined spectroscopically by applying laboratory physics, specifically how atoms behave in a gas.

When scientists first began using laboratory spectroscopes to examine different light sources, they discovered that glowing gases do not emit a continuous spectrum as glowing solids do. Instead, each gas emits light at only certain specific wavelengths, frequencies, and colors. The emission lines evident in a photographic spectrum, or the peaks-and-valleys pattern of a computer-generated line profile (the format of choice today), are a distinct signature of the atoms and molecules that make up the gas. Thus, it is a routine matter for an experienced spectroscopist to examine a spectrum and describe the constituents of the gas that produced the spectrum.

Matter leaves its imprint in a spectrum by either emitting or absorbing radiation. This is accomplished at the atomic level where the interaction of protons, neutrons, and electrons in each atom creates the possibility of only a single set of allowed energy states for that atom. If an atom is given energy by some means (for example, a collision with another atom), it may change from a low energy state to a higher energy state. Later it may get rid of its excess energy, either through another collision or by emitting a photon. But because the atom only has a precisely defined set of energy states available, each photon emission causes the atom to go exactly from one of its states to another. This means that a photon of an exactly defined energy, wavelength, and color will be emitted. In this way the characteristic pattern of emission frequencies is built up for each atom or molecule. This is called an *emission-line spectrum*.

An opposite effect occurs if a continuous spectrum of light passes through a gas with atoms at a very low energy state. Photons may be absorbed, but, as a key fits a lock, only if those photons are of the exact energies needed to take the atoms to well-defined higher energy states. Again an exact pattern of frequencies results, but this time subtracted from the continuous spectrum. This is an *absorption-line spectrum*.

Virtually every star exhibits an absorption-line spectrum superimposed on a continuous spectrum. This has allowed astronomers to create the first reasonably realistic model for the structure of a star. The continuous spectrum is formed in the deepest part of the stellar atmosphere by photons escaping the very opaque, hot, dense stellar interior. However, the atoms and molecules in the gas of the thinner, cooler, more transparent outer stellar atmosphere selectively absorb light at certain frequencies, producing the absorption spectrum. In addition to giving us clues to the structure and chemical composition of stars, absorption spectra also give the basic data for determining all the stellar quantities listed previously, including densities and rotational velocities.

Temperature and Density Effects

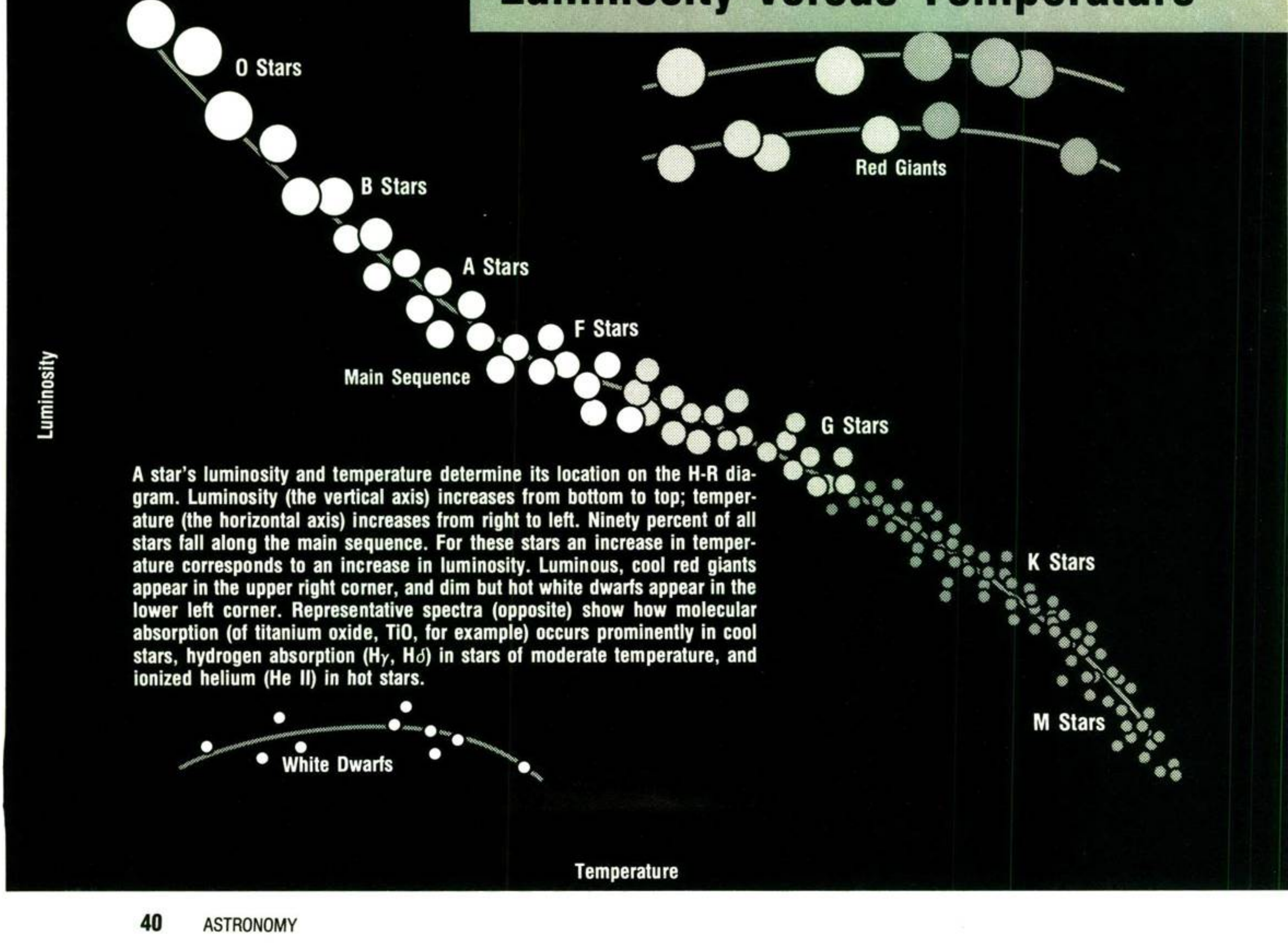
If you look at the spectra of many stars and simply try to describe what kinds of absorption patterns are present, the results can be very discouraging at first. Each star seems to exhibit absorption by completely different sets of atoms and molecules. Your first suspicion may be that the chemical composition of the atmosphere of each star is completely different.

The spectroscopists of the early twentieth century were faced with this dilemma and so obeyed the first impulse of astronomers when faced with new phenomena: they built a classification scheme based simply on the appearance of the absorption-line spectra of stars. From this classification scheme some order began to emerge and a striking correlation was discovered: The principal line-absorption pattern of a star is related to the star's color. And because color is a measure of temperature, the correlation also shows that the surface temperature of a star largely determines the absorption-line spectrum.

The physics behind this result deserves a bit of discussion. Cool, red stars with surface temperatures of 3000 to 4000 kelvins have extensive gaseous atmospheres and thus exhibit spectra rich in molecular absorption. The chief absorbers involved are simple two-atom molecules, such as titanium oxide (TiO), carbon monoxide (CO), and cyanogen (CN). Some absorption is also seen from neutral metallic atoms such as iron, calcium, and so forth. The phrase "neutral atoms" denotes atoms that have all of their normal quota of electrons still bound to the nuclei and thus are electrically neutral.

In sharp contrast to these cool stars are hot, blue stars with surface temperatures of 20,000 to 50,000 kelvins. No molecular absorption is present and neither is absorption by neutral atoms. Instead the absorption spectrum is dominated by neutral helium, ionized helium,

Luminosity versus Temperature

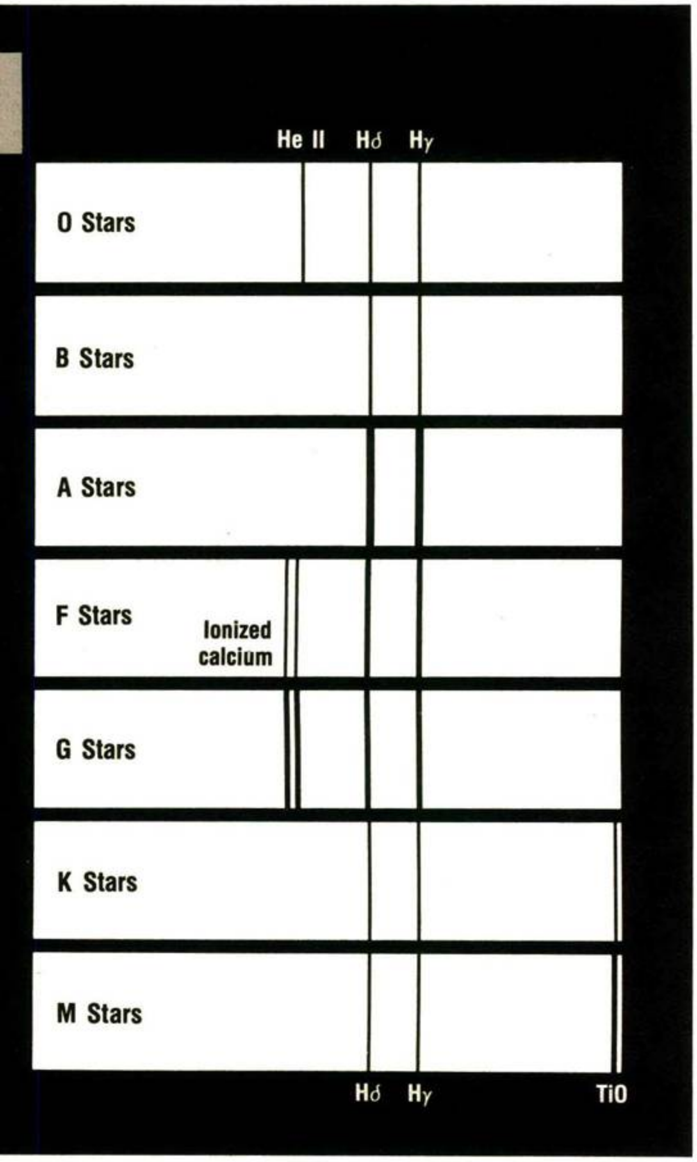


A star's luminosity and temperature determine its location on the H-R diagram. Luminosity (the vertical axis) increases from bottom to top; temperature (the horizontal axis) increases from right to left. Ninety percent of all stars fall along the main sequence. For these stars an increase in temperature corresponds to an increase in luminosity. Luminous, cool red giants appear in the upper right corner, and dim but hot white dwarfs appear in the lower left corner. Representative spectra (opposite) show how molecular absorption (of titanium oxide, TiO, for example) occurs prominently in cool stars, hydrogen absorption ($H\gamma$, $H\delta$) in stars of moderate temperature, and ionized helium (He II) in hot stars.

and highly ionized states of other atoms.

These two extremes in stellar conditions explain the varying spectral patterns. Molecules can only exist in cooler stellar atmospheres. If the temperatures are too hot, there will be both an increasing number of higher-energy photons coming from the stellar interior and an increasing number of energetic collisions among all the atoms and molecules. These two energy sources are sufficient to break the fragile bonds holding the molecules together.

At the extremely hot end of the stellar temperature scale, helium (and especially ionized helium) can only be induced to absorb light in extremely energetic conditions. Atoms such as helium have extremely tight bonds between their nuclei and their electrons. Hence, they do not willingly bond with other atoms (which often involves sharing electrons between atoms), nor do they allow their electrons to become dislodged from the lowest energy states unless they ingest a very large amount of energy. Therefore the absorptive presence of helium will not show up in a stellar spectrum unless the star being examined is very hot. This does not mean that helium is not present in the atmosphere of a very cool star, but it does mean that helium cannot directly "announce" its presence spectroscopically.



There is even a preferred temperature (about 10,000 kelvins) for the formation of absorption features of hydrogen, which typically accounts for nearly 70 percent of a star's mass. If the star's atmosphere is extremely hot, then hydrogen becomes totally ionized and no hydrogen absorption can be detected. If the atmosphere is too cool, then the hydrogen atom's single electron is held tightly bound near the nucleus and never receives enough energy to kick it into an orbit where it could possibly absorb visible light.

The point is that spectral absorption features for any given atom or molecule appear only within an ideal range of stellar temperatures. The stellar classification scheme, in essence, reflects the absorption strength or weakness of the prominent atoms in stars of different temperature.

The gas density (or pressure) in a star's atmosphere also produces an effect on the appearance of a star's spectrum, although it is less pronounced. The balance between the numbers of neutral and ionized atoms in a gas is a sensitive function of both temperature and pressure. At any given temperature the higher the density, the more likely that ionized atoms may recombine with free electrons that happen to be nearby, thus becoming neutral again. So at higher densities, stellar spectra show absorption by neutral atoms more than ionized ones.

The Spectral Sequence

By now we have built up knowledge of several observed quantities of a star: temperature, luminosity, size, and density. The combination of just these quantities points the way to many important insights about stellar evolution. In the early 1900s, once color temperatures and absolute luminosities had been determined for a reasonable number of nearby stars, it occurred, independently and simultaneously, to the Danish astronomer Ejnar Hertzsprung and the American astronomer Henry Norris Russell that these two quantities were related. Simply put, most of the hotter stars were brighter than the cooler ones. More than half a century later this original conclusion remains largely unchallenged. For this reason the plot of temperatures and luminosities of stars, the most basic correlation of all of stellar astronomy, is named the Hertzsprung-Russell, or H-R, diagram.

The H-R diagram on this page is presented in the traditional manner, with luminosity increasing from the bottom to the top of the diagram and temperature increasing from right to left. However, we could label the horizontal axis as color or spectral class. So far we have deliberately avoided mentioning spectral class, but now we must, because this is an article about spectroscopy!

In the early days of spectral classification the meaning of the features in an absorption spectrum was not as obvious as it is today. Therefore the first classification attempts assigned letter designations to the various major types of stellar absorption spectra. The history of these designations is slightly beside the point here. Just note that these letter classes, when correlated with stellar colors and temperatures, are O, B, A, F, G, K, and M in order of decreasing temperature and increasingly red color. We still classify stars with these letters, and generations of astronomy students have memorized the order of these letters with the aid of the standard mnemonic "Oh Be A Fine Girl, Kiss Me." These letters, however, are not terribly descriptive, and the reader would be far better off concentrating on stellar temperatures and colors, which provide much more fundamental physical insight about stellar atmospheres.

The H-R digram is an involved figure that fittingly contains parts of all of our discussions so far. Notice first the long band of stars stretching from the lower right hand corner (the cool, dim stars) to the upper left hand corner (the hot, bright stars). This band is called the *main sequence* because the temperatures and luminosities of about 90 percent of all stars fall along it. This represents the main correlation discovered by Hertzsprung and Russell and is the dominant feature of the spectral sequence of stars. If you study the main spectral features of different stars on the main sequence, you can see the changing absorptions from molecules at the lower right to helium at upper left, which reflects our earlier discussion of the effects of changing temperatures on glowing solids.

As it turns out, the hotter main-sequence stars are also more massive than the cooler ones. The bright blue main-sequence stars are up to fifty times more massive than the Sun, and the dimmest red stars are no more than a few percent of the Sun's mass. Thus the main sequence actually shows larger stars at the upper left and smaller stars at the lower right.

Spectroscopists quickly found some exceptions to the general trends in the H-R diagram, stars that simply would not fit on the main sequence. Generally these exceptions fall into two main categories: a set of stars in the upper right, which are cool yet very luminous, and those in the lower left, which are just the opposite — hot yet extremely dim. These stars, although comprising only 10 percent or so of the stars in the sky, consume the majority of modern stellar research precisely because of their deviance from the main sequence! Their peculiarity in the H-R diagram is a real signal of their anomalous evolutionary states. Generally they represent stars in various stages of old age, though a few of the luminous, cool stars are actually stars in extreme infancy.

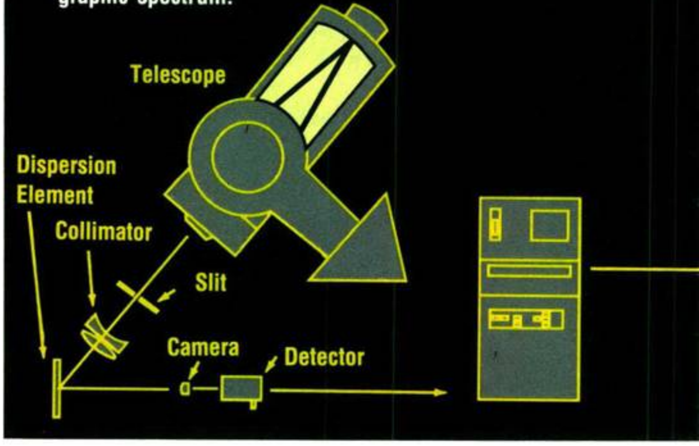
We have come to call the stars populating the upper right-hand corner of the H-R diagram "red giants." Why? A recapitulation of the arguments about the sizes of glowing solids provides the answer. The "red" is obvious from their colors and, to astronomers, red is synonymous with cool surface temperatures. As mentioned before, a cool surface temperature also means that the amount of energy emerging per unit area from such a star is small. However, observations, which show that these stars are bright, demand that the *total* amount of emitted radiation must be very large. The only way to reconcile low-energy output with bright-light output is to insist that the total surface area of the star be large; the star *must* be a giant. We can reverse these same statements — high-energy output, faint-light output — to justify the name "white dwarf" for the hot, dim stars of the lower left-hand corner of the H-R diagram.

It is easy to distinguish the physical characteristics of red giants from the smaller red main-sequence stars. The giants have masses comparable to stars on the main sequence, but over periods of billions of years they have evolved *off* the main sequence. As they have aged, their outer envelopes have expanded, and therefore their atmospheres are less dense and have lower pressures than typical main-sequence stars.

From Star to Spectrum

More than a simple prism is needed to analyze starlight. With a spectrograph the telescope delivers the star's light to the focus, where the light encounters the slit of the spectrograph. The size of the slit is one of the determining factors of the resolution (the amount of detail) seen in the spectrum: the narrower the slit, the higher the resolution. The light rays diverge as they pass through the slit but are made parallel again, as they were before encountering the telescope, by the collimator. The parallel rays then strike the dispersion element (a prism, diffraction grating, or combination of both), which separates the light into its component wavelengths.

The light is now a set of parallel beams each set at a different angle according to the characteristic wavelength of each beam. However, for each wavelength the light must be once again brought to a focus. This is accomplished with the camera. The dispersed and focused spectrum is next recorded by a detector, either an electronic silicon diode array or, less popular, film. If the detector is electronic, the signal is sent to a computer and the output appears on the monitor screen and saved to disk. If the detector is film, the result is a photographic spectrum.

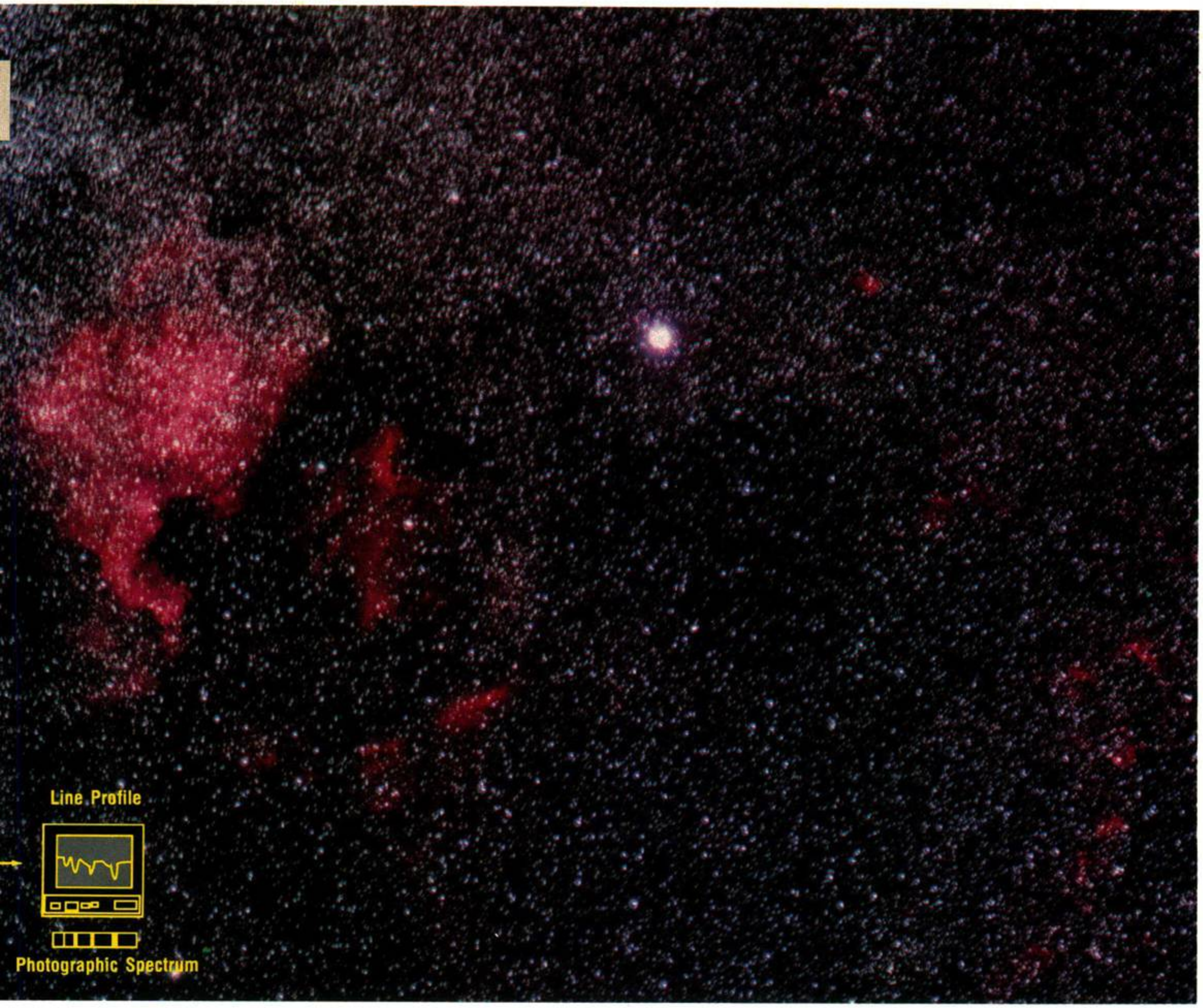


The lower densities and pressures are reflected in different balances between neutral and ionized atoms at the same temperatures and are easily seen on spectra. In this way we have linked together all the stellar quantities. The large, luminous red-giant stars have cool, thin atmospheres, whereas white dwarfs are small, dim objects that have very hot, dense atmospheres. In this manner all the parts of the H-R diagram are filled in, and astronomers can imagine the physical state of any star in any part of the diagram. Some very simple observations have led to nearly complete descriptions of the basic structures of stars.

Star Stuff

Even after the temperature and pressure effects on stellar spectra have been accounted for, some large and small variations in the strengths of absorption features still occur. There are two general categories of these so-called peculiar stellar spectra.

The first peculiarity, shared by many stars in the halo of our Galaxy, is a general weakening of all of the absorption caused by the heavy elements (those other than hydrogen and helium). This absorption weakness is simply due to the fact that these stars are deficient in



heavy elements, sometimes as much as a thousand times less than the Sun. These stars are known to be among the oldest stars in our Galaxy merely by their membership in the galactic halo rather than the disk, where star birth is more prevalent. First-generation stars, those born early in the history of our Galaxy, would have manufactured some heavy elements, but those elements would have remained mainly in their interiors until their deaths. Thus the spectra of early generation stars would show few heavy elements. Later-generation stars would be born with chemical mixes enriched in heavy elements manufactured by their predecessors. The heavy element absorption strength would continue to increase in subsequent generations of stars. Astronomers therefore conclude that there has been an increase in the galactic heavy-element content as succeeding generations of stars have lived, synthesized elements in their interiors, and died, explosively returning their manufactured elements to the interstellar medium.

The spectra of other stars can be selectively enhanced or deficient in a few elements. Some giant stars, for example, bubble by-products of their interior hydrogen and helium fusion cycles up to their surfaces. Thus, some stellar spectra may show enhanced carbon, nitrogen, or some of the very heavy, rare-earth elements like lanthanum or cerium. In some main-sequence stars the various elements separate into different layers by diffusion and a whole variety of enhanced or depleted absorption features of metals may be seen.

Stellar spectroscopists like to find peculiar properties in stellar spectra because the spectra of the overwhelming majority of stars are so regular! The pathological cases tell us much about the limits of possible conditions in stellar atmospheres and interiors.

Velocity Information

Even more can be learned from stellar spectra by the clever application of the Doppler effect. This phenomenon is named for the physicist who demonstrated the effect of sound emitted by moving objects on the perceived frequencies. The Doppler effect is familiar to all of us even though we rarely acknowledge its explanation. The usual examples are blaring train horns or whining truck tires approaching and then receding from us. The pitch of any sound is higher when the object is moving toward us than when it is moving away. Pitch, however, is just another way of saying frequency.

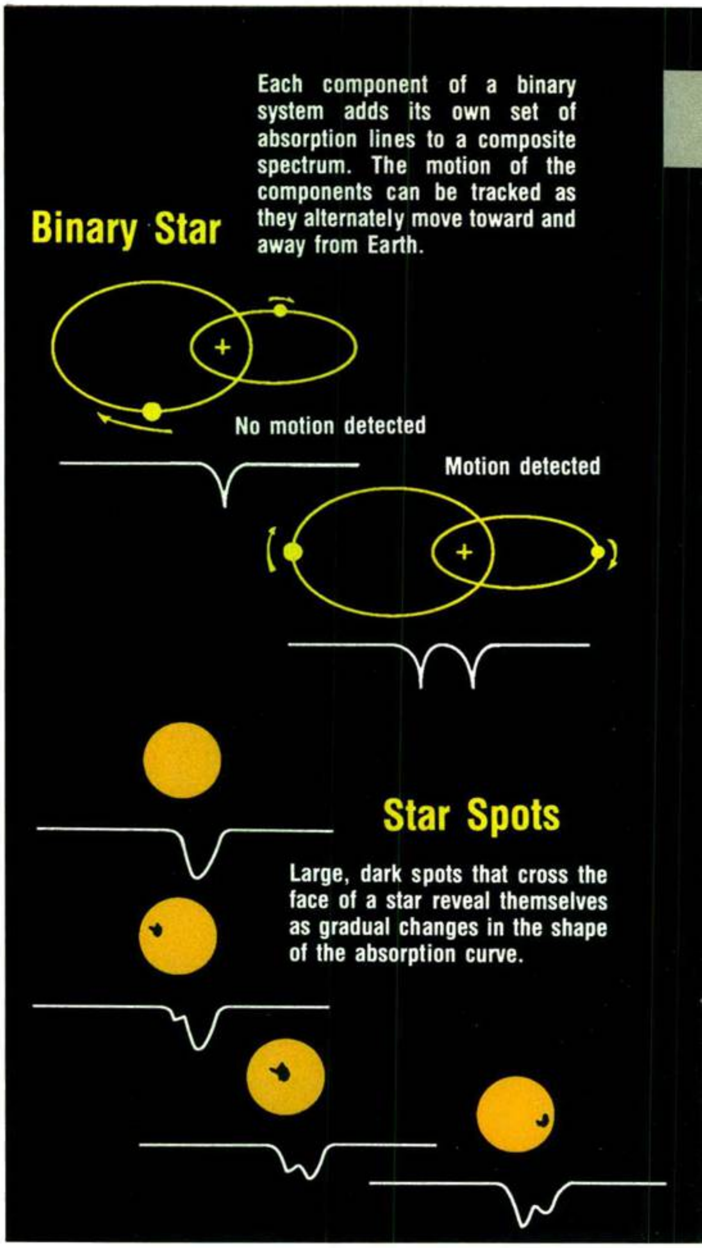
The same rule applies to the frequencies of light as well as of sound. In addition, because the speed of light is constant, we can say that not only are the frequencies of light higher when objects are moving toward us but the wavelengths of light are smaller. If the object is not moving toward or away from the observer, no changes in light frequency/wavelength are noticed. Therefore the Doppler effect is able to give information only on line-of-sight velocities, or *radial* velocities.

The Doppler effect tells us how fast objects are moving along our line of sight. From this we can infer information about the masses of stars in binary orbits, the motions of stars in the Galaxy, the velocities of rotating stars, the turbulent motions in a stellar atmosphere, and the existence and sizes of star spots. In the most straightforward application the relative velocity between a star and Earth can be obtained by careful measurement of the red- or blueshift in wavelength or frequency of the absorption features of the star's spectrum. When a pattern of stellar absorption features has been identified, astronomers compare that star's spectrum to a terrestrial spectrum that shows these same features at their rest frequencies. Then relatively straightforward measurements of the differences between the observed and expected frequencies immediately yield the relative radial velocity of the star.

There are many components to the observed stellar radial velocity. One component is, of course, the star's motion through space. A second component is the Sun's motion through space. Two other velocity factors are the revolution of Earth and the rotation of Earth on its axis. Because the motions of Earth are cyclical on yearly and daily timescales, all observed radial velocities can be corrected for Earth's motion by being referred to the Sun. These overall radial velocities for stars give us information on the motions of stars around the center of the Galaxy, on the peculiar motion of the Sun with respect to the stars nearest the Sun, and on the streaming of different star groups in the solar neighborhood.

Binary star orbits can also be determined with radial velocities. Indeed, some binary star systems are too compact or too far away from Earth to permit detection of both components by visual means. Often spectroscopic observations provide the only means to detect the binary nature of these systems. Each component of a binary star system contributes its own set of absorption lines to a composite spectrum. We can follow the motion of each component as it alternately comes toward and goes away from us.

The chief limitation of this technique lies in the binary system's orbital tilt with respect to Earth. The orbital tilts are random with respect to us, and the members of systems that are "face-on" exhibit no cyclical Doppler motions because they never move toward or away from us during an orbital period. At the other extreme are those stellar orbits that happen to be viewed edge-on by us — eclipsing binaries. Then we see the full effects of the orbital motions in the Doppler shifts of wavelengths and frequencies in the spectra.



Binary Star

Each component of a binary system adds its own set of absorption lines to a composite spectrum. The motion of the components can be tracked as they alternately move toward and away from Earth.

Star Spots

Large, dark spots that cross the face of a star reveal themselves as gradual changes in the shape of the absorption curve.

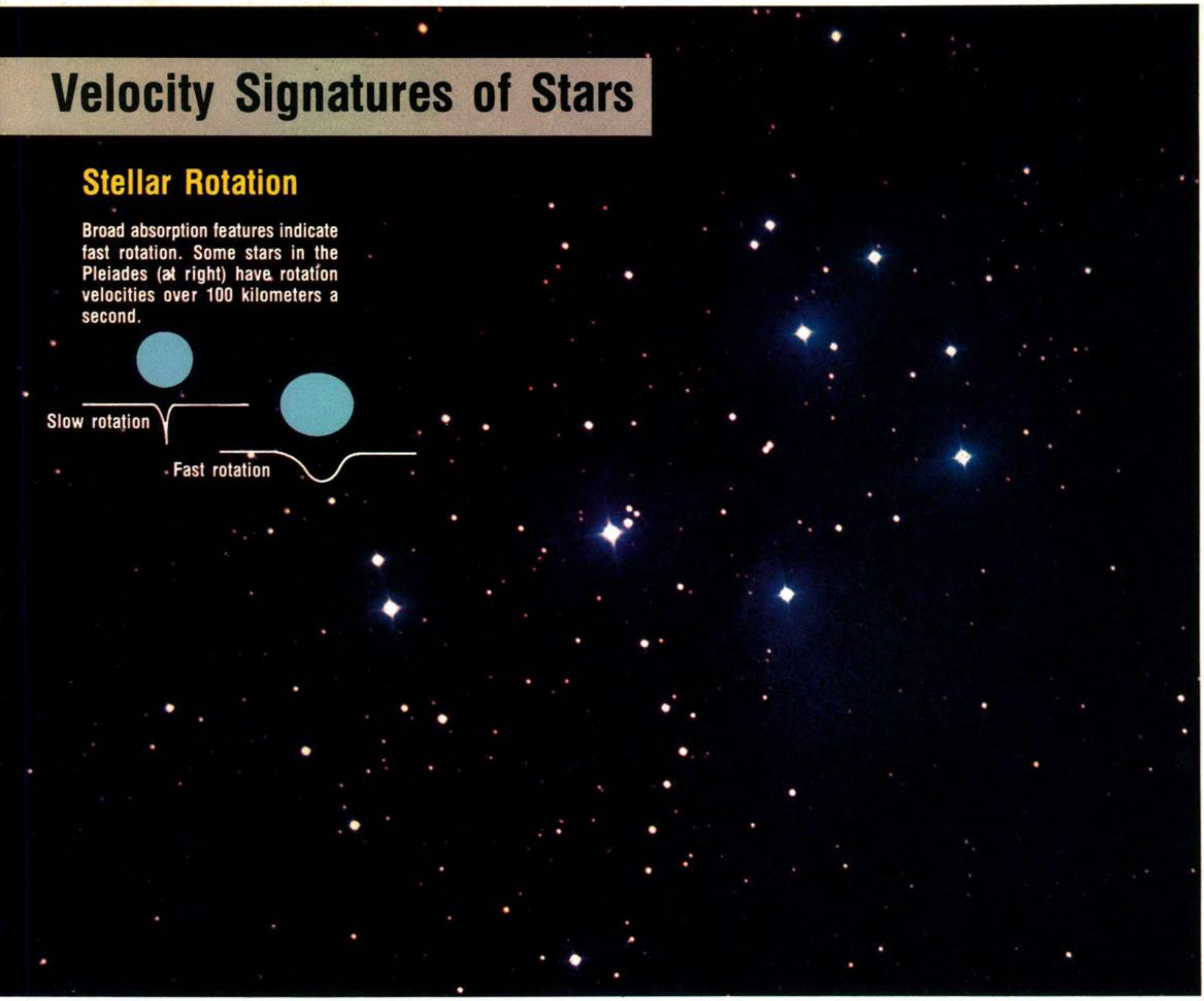
The star's rotational velocity is another piece of information derivable from Doppler shift measurements. The stars we see as pinpoints of light are, in fact, hundreds of thousands and even millions of miles in diameter. The bundle of photons that make up each point actually comes from widely separated areas on the surfaces of the stars. From what we have learned about the Doppler effect, it should be clear that just as the total motions of different stars affect the received frequencies of light, so do the differential motions of various parts of the surface of a single star.

For example, imagine a distant star is oriented so that its pole is vertical and its equator is horizontal with respect to our line of sight. The star's rotation creates an instantaneous movement toward us by material on one limb (blueshift), movement away from us by the material on the opposite limb (redshift), and no net line-of-sight movement by the material at the center of the stellar disk. Each part of the surface contributes its own absorption feature at a slightly different frequency than other parts of the surface. The addition of the contributions from all parts of the surface produces an absorption feature that is smeared out in frequency, and the higher the rotation, the broader the absorption feature.

The measurements of the frequency widths of stellar absorption features have shown that some stars rotate on their axes at *hundreds of miles a second.* Unfortunately the same orientation effects that limit our ability to use spectroscopy as a diagnostic tool on binary stars also hamper our efforts to describe completely the rota-

Velocity Signatures of Stars

Stellar Rotation



Broad absorption features indicate fast rotation. Some stars in the Pleiades (at right) have rotation velocities over 100 kilometers a second.

tions of stars. Imagine if the star's rotation axis were to point at us (so we view the star "pole on"). Then the rotation would describe a circular motion and no part of the star would undergo a line-of-sight motion toward or away from Earth. Even if the star were rotating at a very high rate of speed, there would be no Doppler broadening of the absorption features.

Astronomers, therefore, are limited to making statistical arguments about stellar rotation. It is hoped that if a large enough sample of stars is surveyed, at least some of those stars will be oriented "equator on" so the maximum limits of stellar rotation speeds can be studied. However, it must be stressed that for no star may astronomers unambiguously give its total rotation speed: the speed is what is measured or greater, depending on the pole orientation.

Finally, the Doppler effect may be employed in this same manner to probe the large- and small-scale random motions of stellar atoms in a stellar atmosphere. In the atmosphere of even a nonrotating star the turbulent conditions create pockets of rising and falling gas. (The shifting granulation patterns observed on the Sun are the best examples of this phenomenon.) The atoms in these pockets absorb light at slightly different frequencies, and a Doppler-smeared absorption profile inevitably results.

That so many physical details can be gleaned from a feeble point of light lends an almost mystical air to the field of spectroscopy. However, mysticism has nothing to do with the results! Systematic observation remains the key to all our insights about stars. What astronomers have learned about the formation of stars, their subsequent lives and deaths, and the origin of the elements did not spring from nothing. Rather, the knowledge was literally read from starlight.

The analysis of light means everything to astronomers. Spectroscopy not only puts us in touch with the physical reality of the stars, but it significantly broadens our understanding of the universe. The message of starlight, once thought indecipherable, is indeed rich in information that ancient astronomers could not have imagined. □

Christopher Sneden is an associate professor of astronomy at the University of Texas. His research specialty is the chemical compositions of stars.

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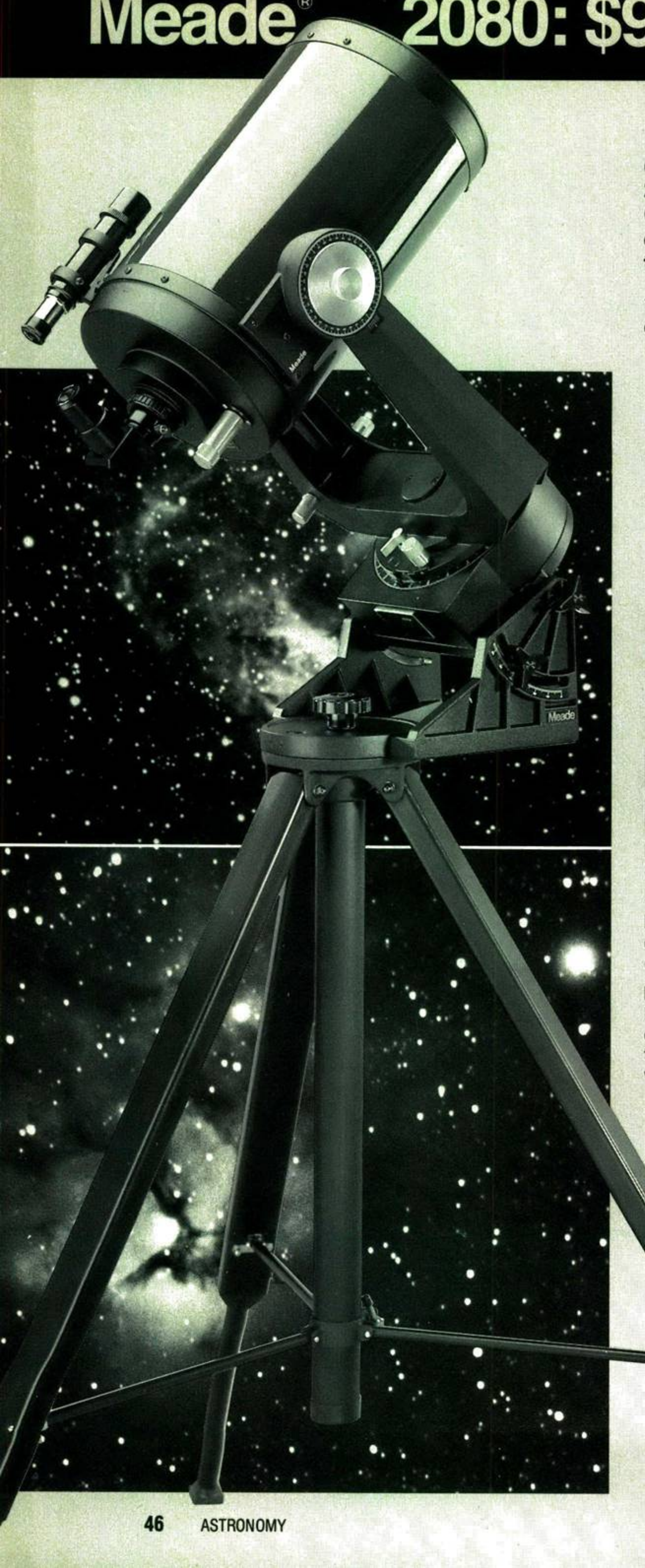

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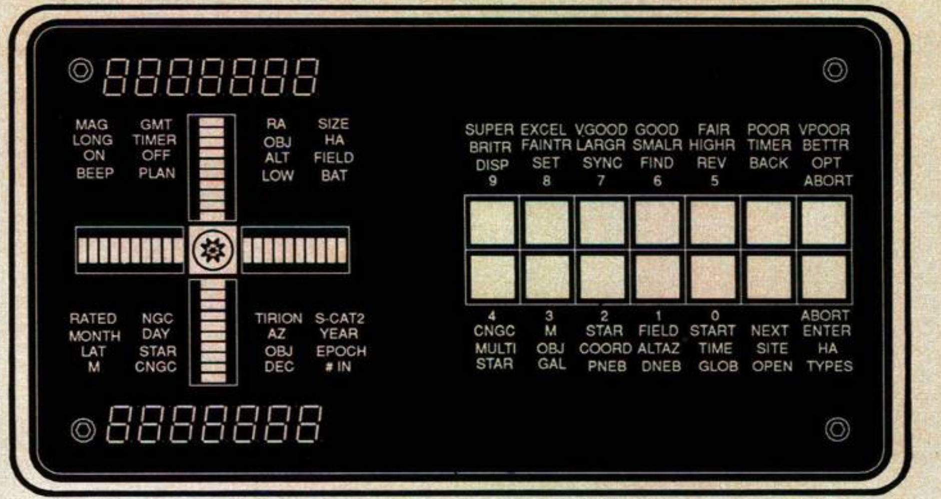
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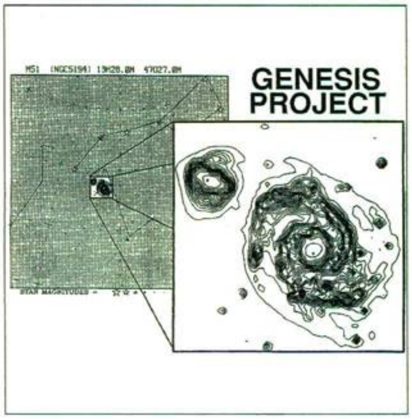

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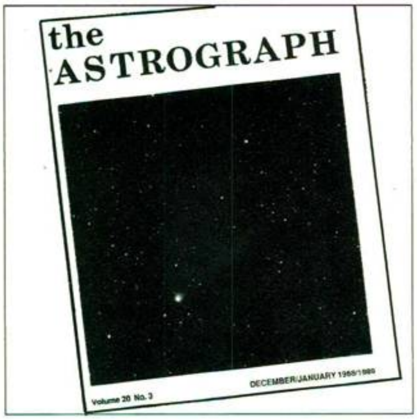

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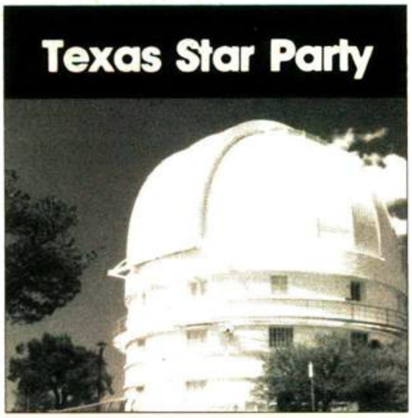

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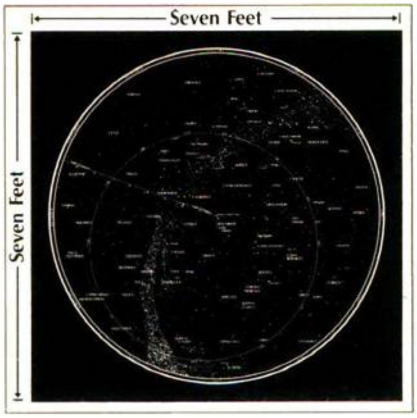

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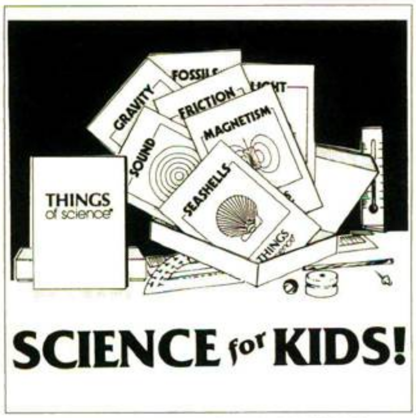

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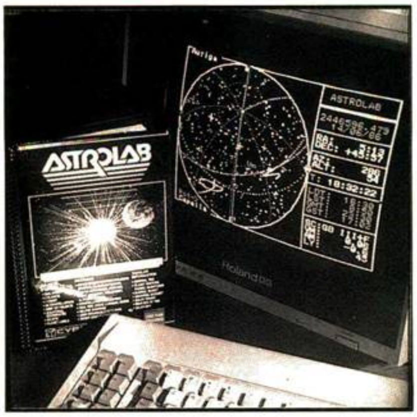

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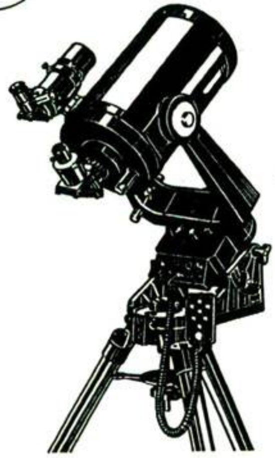

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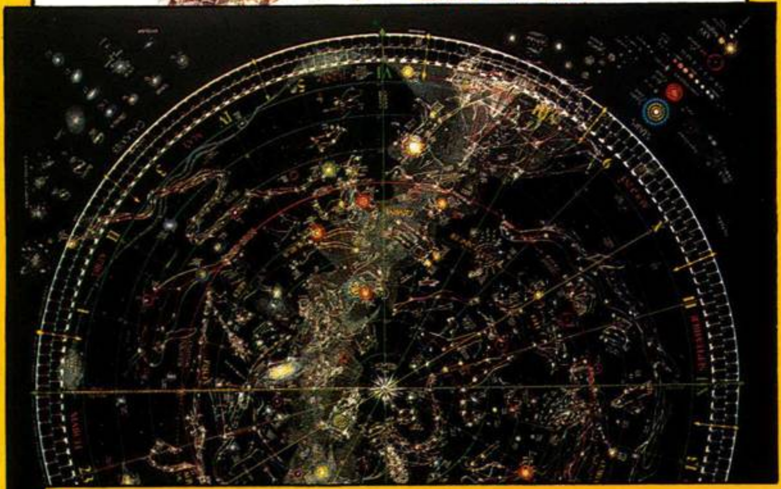

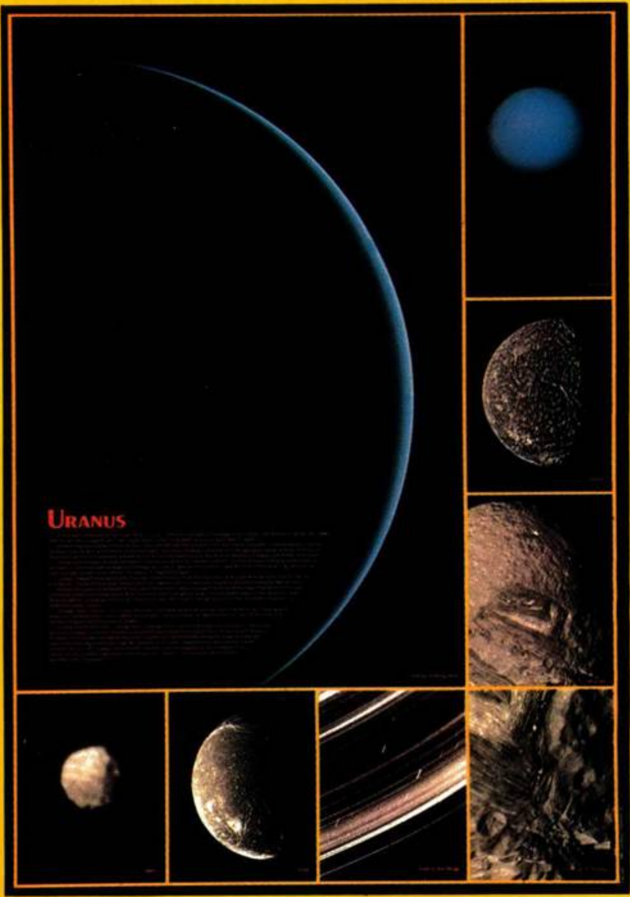

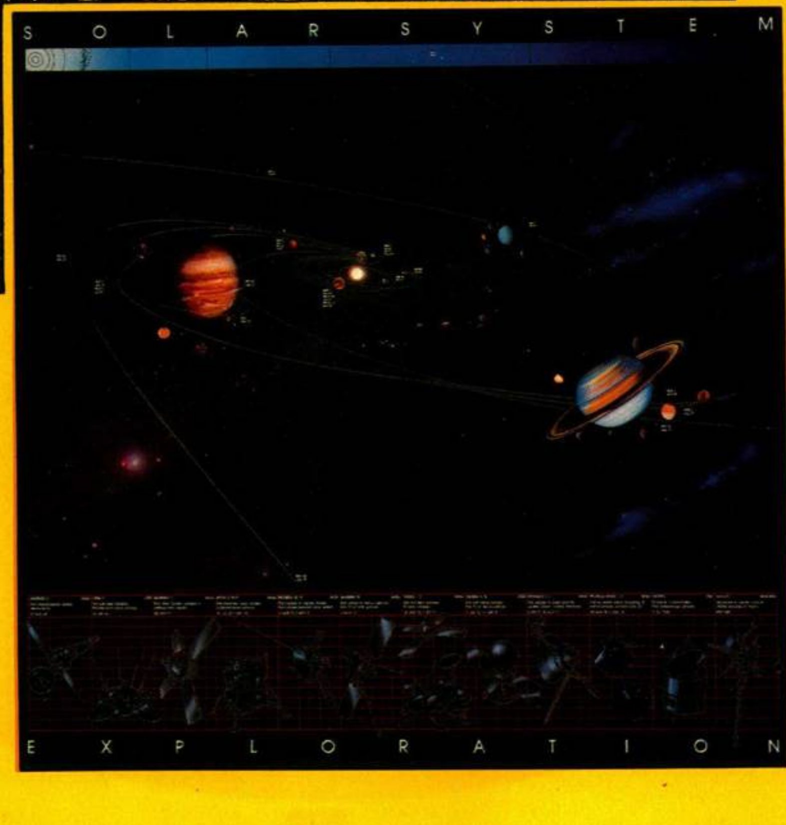

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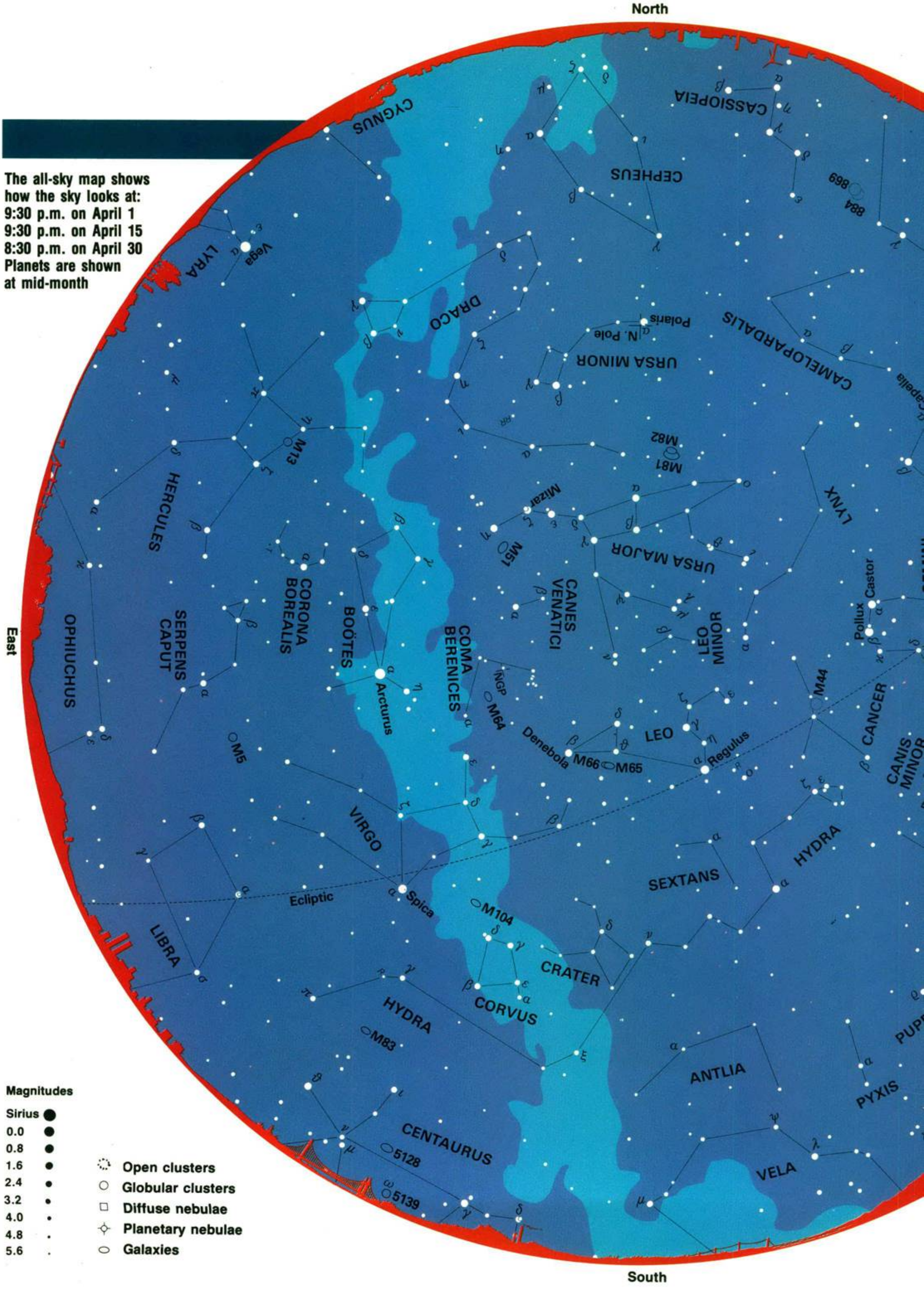
The all-sky map shows how the sky looks at:
9:30 p.m. on April 1
9:30 p.m. on April 15
8:30 p.m. on April 30
Planets are shown at mid-month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South
East
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CASSIOPEIA
CEPHEUS
869
884
LYRA
Vega
DRACO
Polaris
N. Pole
URSA MINOR
CAMELOPARDALIS
Capella
M82
M81
M13
HERCULES
Mizar
URSA MAJOR
LYNX
M51
CORONA BOREALIS
BOÖTES
CANES VENATICI
LEO MINOR
Castor
Pollux
OPHIUCHUS
SERPENS CAPUT
COMA BERENICES
NGP
Arcturus
M64
M44
CANCER
M5
Denebola
LEO
Regulus
M66
M65
CANIS MINOR
VIRGO
HYDRA
SEXTANS
Ecliptic
Spica
LIBRA
M104
CRATER
CORVUS
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3.2 •
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Open clusters
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□ Diffuse nebulae
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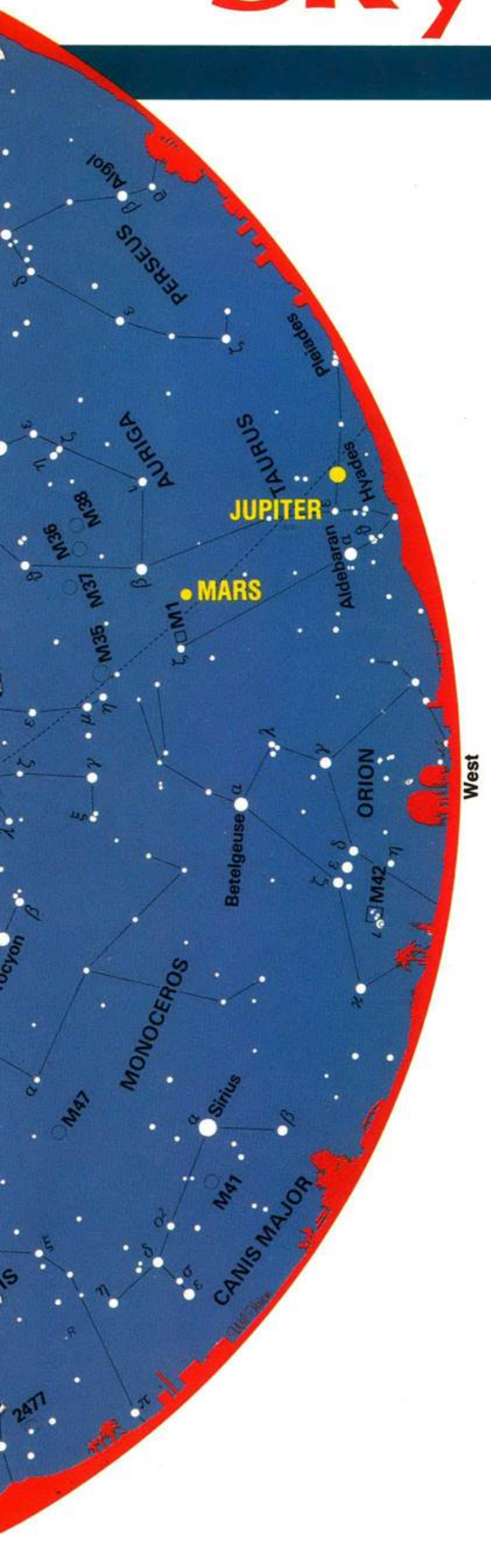
APRIL 1989



Map Art by Wil Tirion

MERCURY AT ITS BEST

Mercury is easy to find in the evening sky of late April and early May during its best apparition of 1989. Look for the innermost planet about forty-five minutes after sunset in the twilight glow of the west-northwest.

A BUSY MONTH FOR THE MOON

The Moon occults three prominent objects in April. First, on the evening of April 8, the Pleiades are covered by the Moon. Five days later the Beehive Cluster in Cancer is the victim. Both events are visible from northeastern North America. Finally, on April 15, 1st-magnitude Regulus is occulted for observers in the southeastern United States.

VIEW THE SLIM CRESCENT MOON

On the evening of April 6, just one day after New Moon, a very young Moon may be visible right after sunset. Look for the slender crescent in the brightest area of the twilight glow about a half to three quarters of an hour after sunset.

SPOT SINKING JUPITER

Jupiter's lengthy stay in the evening sky is now drawing to a close. April is the last full month when the giant planet, still located in Taurus, is well placed for viewing in the western evening sky.

Dates and Times

4 Mercury is in superior conjunction
Venus is in superior conjunction

5 The Moon is at perigee (221,949 miles from Earth)
New Moon is at 11:33 p.m. EDT

8 The Pleiades are occulted by the Moon

10 The Moon passes 4° north of Mars, 5 a.m. EDT

12 First Quarter Moon is at 7:13 p.m. EDT

15 Regulus is occulted by the Moon, 5 p.m. EDT

18 The Moon is at apogee (252,380 miles from Earth)

20 Full Moon is at 11:13 p.m. EDT

22 Lyrid meteor shower peaks this morning
Saturn is stationary

24 The Moon passes 0.5° south of Antares, 3 a.m. EDT

26 The Moon passes 5° south of Saturn, 7 p.m. EDT

28 Ceres is in conjunction with the Sun
Last Quarter Moon is at 4:46 p.m. EDT

30 Mercury is at greatest eastern elongation (21°)

Eye on the Sky by Deborah Byrd

JUPITER'S LAST GOOD MONTH

April is the last month Jupiter will be prominent in the evening sky. The planet lingers in the west after sunset, but it appears a bit lower in the sky at the end of each day. Still, Jupiter is unmistakable at magnitude −2.0, shining brilliantly from what has become its familiar spot in the constellation Taurus.

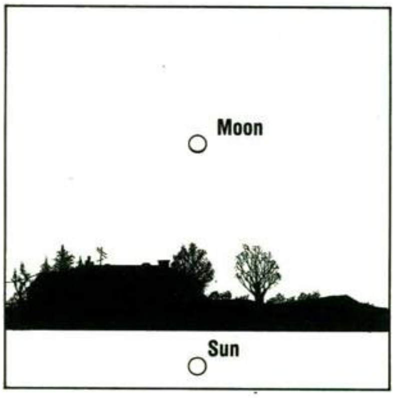
Jupiter has been in the evening sky for many months while Earth in its smaller and faster orbit around the Sun has gradually pulled ahead of the giant planet. Now we are so far ahead of Jupiter that the distance between us and the largest planet is very great, and the Sun is about to come between the two worlds. Next month the giant planet will appear to back into the Sun's glare and be lost from view.

MERCURY BRIGHT IN THE EVENING SKY

Toward the end of April, before Jupiter has a chance to move offstage, another planet rushes up out of the sunset glare to appear below Jupiter in the twilight sky. Mercury, the most elusive of the bright planets, has its best apparition of 1989 in late April and early May.

At greatest elongation on the evening of April 30, Mercury appears 21° east of the Sun. Forty-five minutes after sunset it still lies a respectable 11° above the horizon, almost directly above the sunset glow in the west-northwest. You therefore have a good chance of seeing Mercury, something relatively few people have ever done. Mercury rushes in and out of our sky so quickly and rarely appears in a truly dark sky, so you have to know just when and where to look for it.

The brightness of Mercury may surprise you. It shines most brightly at about magnitude −1.0 as it comes up out of the twilight glare in midmonth. It gets dimmer as the days pass but still shines respectably at magnitude +0.2 on April 30.



SPOT THE ONE-DAY-OLD MOON after sunset on April 6, when the thin crescent lies just above the horizon in bright twilight (above). Dewey Vanderhoff captured the crescent Moon, lit by earthshine, with Mercury in October 1982 (below).

CATCH THE YOUNG MOON

Mercury is especially easy to see this month because in the spring the ecliptic — the apparent path of the Sun across the sky and the approximate path of the Moon and planets — stands nearly straight up from the western horizon after sunset. That also makes April a good time to look for a very young Moon.

The Moon is New, at its closest to being between the Sun and Earth, on the evening of April 5. Early on the evening of April 6 the young Moon makes a brief appearance in a sky still brightly lit with twilight. You'll need clear skies and a flat horizon to spot the slender crescent. Binoculars will also help (focus them on the most distant visible object). Scan along the western horizon right after the Sun goes down; the Moon will appear where the twilight glow is brightest. As the sky darkens, you might be able to see the Moon with your eye alone.

APRIL'S PLANETS

Jupiter is easy to see in the west after sunset. It is brighter than any star and occupies a prominent position in our sky in the constellation Taurus.

The planet still appears wedged between the two famous star clusters, the Pleiades and the Hyades. Despite their apparent proximity, however, you should remember that while Jupiter is less than 1 light-hour away, neither cluster is closer than 100 light-years to Earth. The Pleiades appears as a tiny dipper of stars. The Hyades have the shape of the letter "V".

Jupiter, along with these clusters, is now sinking into the twilight glare. They will all disappear from view in May.

A second planet lies in Taurus this month. Mars, at magnitude +1.5, is much fainter than Jupiter and appears above the other planet in the western twilight sky. Don't confuse Mars with the red star Aldebaran, which marks the eye of Taurus the Bull. Aldebaran is a bit brighter and it twinkles, while Mars shines steadily.

Even though Mars is less prominent than Jupiter and Aldebaran, it will remain in the evening sky long after these two objects disappear. This planet is now moving rapidly toward the east in front of the stars. As Jupiter and the stars of Taurus sink out of view next month, Mars will abandon ship and cross into the constellation next door, Gemini. By continuing this rapid eastward motion, Mars will manage to stay in view through most of next summer.

Located in the constellation Sagittarius, Saturn remains in one of the most star-cluttered regions of the Milky Way. The planet rises after midnight and can be found in the southeast at dawn.

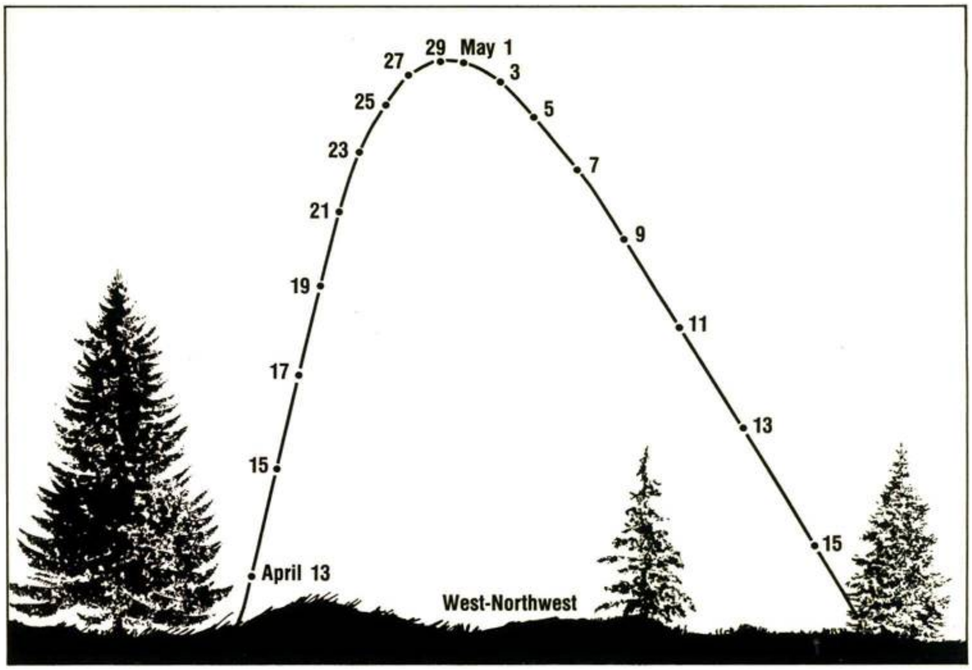
This month there are several harbingers that Saturn is getting closer to its early July opposition, when Earth will pass between Saturn and the Sun. The planet appears stationary in front of the background stars on April 22 and afterward begins moving retrograde, or westward, in front of the stars.

The beginning of retrograde motion for an outer planet means that Earth is quickly gaining on the planet in the race around the Sun. Between now and September, as though we are riding a faster horse on an inside track, Saturn will appear to move backward against the more distant "landscape" of stars.

There are two more signs that Saturn is approaching opposition. First, it brightens from magnitude +0.5 to +0.4 in April and will continue getting brighter until July. Second, Saturn continues to rise earlier. In fact, if it weren't for the beginning of daylight-saving time in April, we'd find Saturn rising before midnight by the end of the month.

Both Mercury and Venus pass behind the Sun from our earthly vantage point on the same day, April 4. Mercury, the innermost planet, moves faster than Venus, however. Its rapid motion is accentuated this month because it reaches perihelion, its closest point to the Sun and the time when it moves fastest in its orbit, on April 15.

Thus, although Venus will not be visible in the evening sky until next month, Mercury comes into view after sunset around the middle of April. It appears a little higher in the sky each evening and by the end of the month is clearly visible at greatest elongation below brilliant Jupiter.



MERCURY'S BEST APPARITION of 1989 occurs in late April and early May. Look for the elusive planet, which reaches a maximum elevation of 11° on April 30, low in the west-northwest about forty-five minutes after sunset.

APRIL'S STARRY SKY

Nearly everyone can find the Big Dipper, now high in the northeast during the evening hours. This famous asterism in the constellation Ursa Major, the Great Bear, consists of seven fairly bright stars in the shape of a dipper.

If you let your eyes trace out the handle of the Big Dipper and then extend this arc outward by about 30°, you will come to a prominent star of the springtime sky, Arcturus in the constellation Bootes. In other words, "follow the arc to Arcturus."

Arcturus, which means "Guardian of the Bear," is often said to be yellow in color, although to me it has always looked more orange. It has a somewhat lower surface temperature than our Sun, but its diameter is twenty-five times greater, which makes it one hundred times brighter than our Sun. It shines as the fourth-brightest star in our sky from a distance of 36 light-years.

Arcturus is bright and beautiful, and the pattern of its constellation Bootes the Herdsman is easy to pick out. The constellation looks very much like a large kite.

Perhaps the most interesting thing about Arcturus is something the eye cannot detect: the star has a much larger proper motion than most other stars.

All the stars in our sky move through space, pursuing their endless circuits around the center of the Galaxy. But most visible stars are like the Sun in that they are located in the flat disk of the Galaxy. They drift in the same general direction through space like fallen leaves drifting downstream. Thus, we can detect only a very slow motion of the stars with respect to one another. For most purposes they appear "fixed."

Arcturus, on the other hand, is not a disk star. Instead, it is a temporary visitor to our region of the Galaxy and became visible to the naked eye an astronomically short time of only half a million years ago.

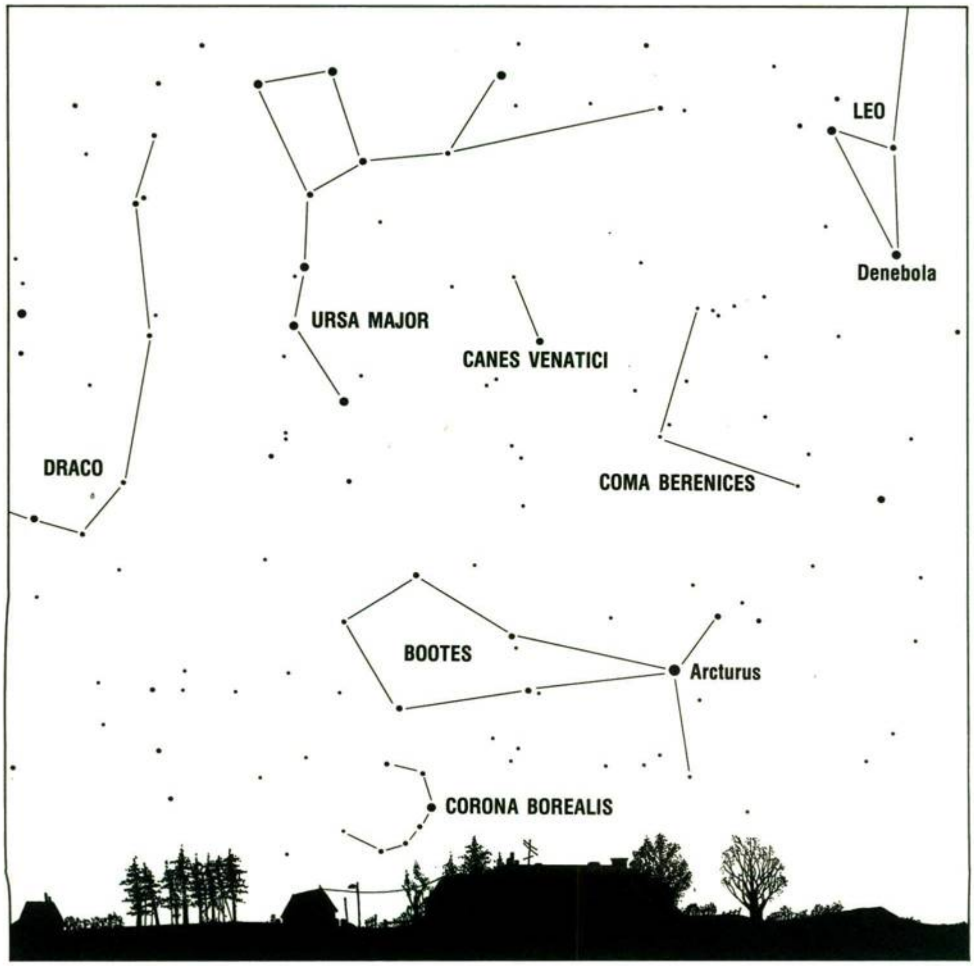
It belongs to a great halo of stars that also orbits the center of the Galaxy. Halo stars pass up and down through the disk, slicing through it like warm knives through butter with periods of hundreds of millions of years.

Arcturus is now passing through the galactic disk with a velocity of some 100 miles per second relative to our Sun. Thus its proper motion, or sideways motion with respect to other stars in our sky, is very large. It moves an apparent distance of about one tenth of a Full Moon-diameter about every seventy years. This proper motion is so astoundingly fast compared with the proper motions of other stars that it was first detected by Edmond Halley in 1718.

It's fun to contemplate Arcturus, a great yellow-orange globe rushing past us in the night. Only the vastness of space and time and our minuscule place therein prevent us from seeing it go by.

Also, imagine how the sky must look from the vicinity of this star. Over a period of millions of years, innumerable stars must appear to sweep past it like a movie of stars on a suddenly illuminated screen, which will go dark once more when Arcturus plunges on into the relative emptiness outside the disk of the Galaxy. ☐

THE THIRD-BRIGHTEST STAR in the sky, Arcturus, lies low in the northeast as April evenings begin. To locate the star, follow the "arc to Arcturus" by extending the handle of Ursa Major's Big Dipper about 30° away from the bowl.



Through the Eyepiece by Rick Shaffer

A PLETHORA OF LUNAR OCCULTATIONS

The Moon's motion through our sky brings Earth's only natural satellite in front of two superb deep-sky objects and two 1st-magnitude stars in April. Three of these events are visible from parts of North America.

The first and most interesting occultation is of the Pleiades star cluster (M45) the evening of April 8. The Moon, just three days past New Moon, will be 12 percent lit, so its light will not overwhelm the cluster. And the slender crescent Moon will be waxing, which means individual stars will disappear behind the Moon's dark limb. A dark-limb disappearance is much easier to observe than a bright-limb disappearance because glare from the Moon is so much less.

Observers in the northeastern United States and eastern Canada have the best view of the occultation as the Moon crosses the northern part of the Pleiades. Two of the six naked-eye Pleiads, 4th-magnitude 19 Tauri (Taygeta) and 20 Tauri (Maia), are occulted from this region. Farther south, observers can see the Moon traverse the cluster's northern edge just north of the dipper-shaped asterism. Observers in the west will miss the occultation; however, they can still see the slim crescent to the northeast of the cluster after darkness falls.

Although the Pleiades cluster is a naked-eye object, you'll need sturdily mounted binoculars or a telescope to see the individual stellar occultations. Be ready to observe as soon as the sky gets dark — the Moon is already near the cluster by that time. If you live in the northeast, you can see 18, 19, and 20 Tauri disappear between about 9:30 and 10 p.m. EDT. Only the disappearances of these stars are visible because the Moon and the Pleiades set before the stars reappear.

Five days after the Pleiades occultation the gibbous Moon slides in front of Cancer's Beehive Cluster (M44). Located about halfway between the stars Regulus in Leo and Pollux in Gemini, the Beehive is fainter (its brightest star is 6th-magnitude Epsilon [ε] Cancri) and more tightly packed than the Pleiades. This means the Beehive occultation will provide more activity in less time than the Pleiades occultation.

The Moon follows a path through the northern part of the Beehive at approximately 11 p.m. EDT on April 13. As with the Pleiades occultation, observers in northeastern North America have the best view of the event, while observers south and west will see a close passage. Begin observing shortly after darkness falls and continue until the Moon is well past the cluster.

The Moon, now one day past First Quarter, is still waxing, so all stellar occultations are dark-limb disappearances. However, the 61 percent-illuminated Moon is much brighter than the 12 percent-lit Moon was five days earlier, which makes the occultation a telescopic event.

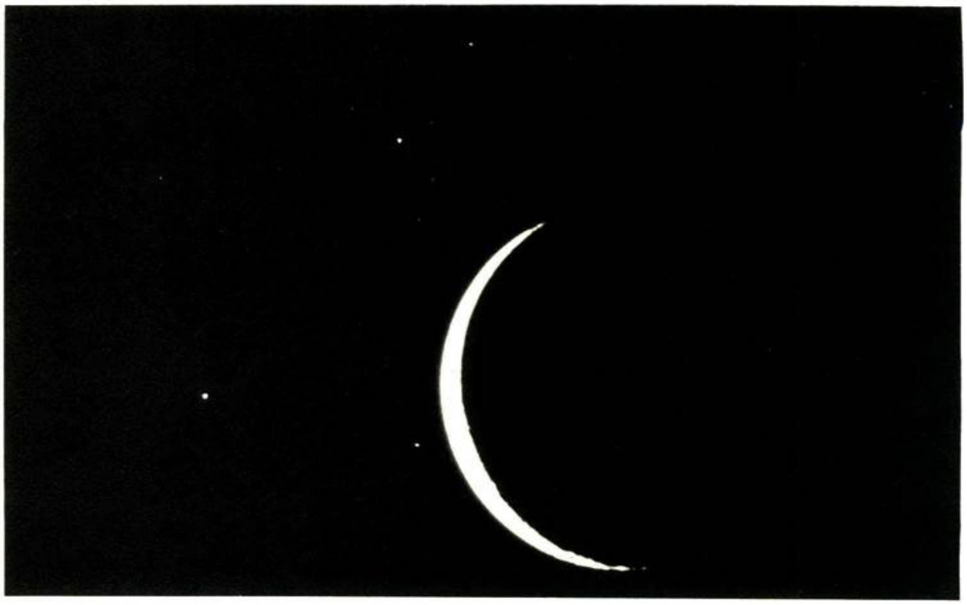
The last major occultation visible from North America in April occurs on the afternoon of the 15th, when the Moon hides 1st-magnitude Regulus. Because the occultation occurs during daylight hours, you'll need a telescope to pick out Regulus in the blue sky. The Moon is a 78 percent-lit waxing gibbous in the east.

Observers along a line passing through central Virginia, southern West Virginia, central Kentucky, the southern tip of Illinois, southern Missouri, and northern Oklahoma can see a grazing occultation. Observers there may see

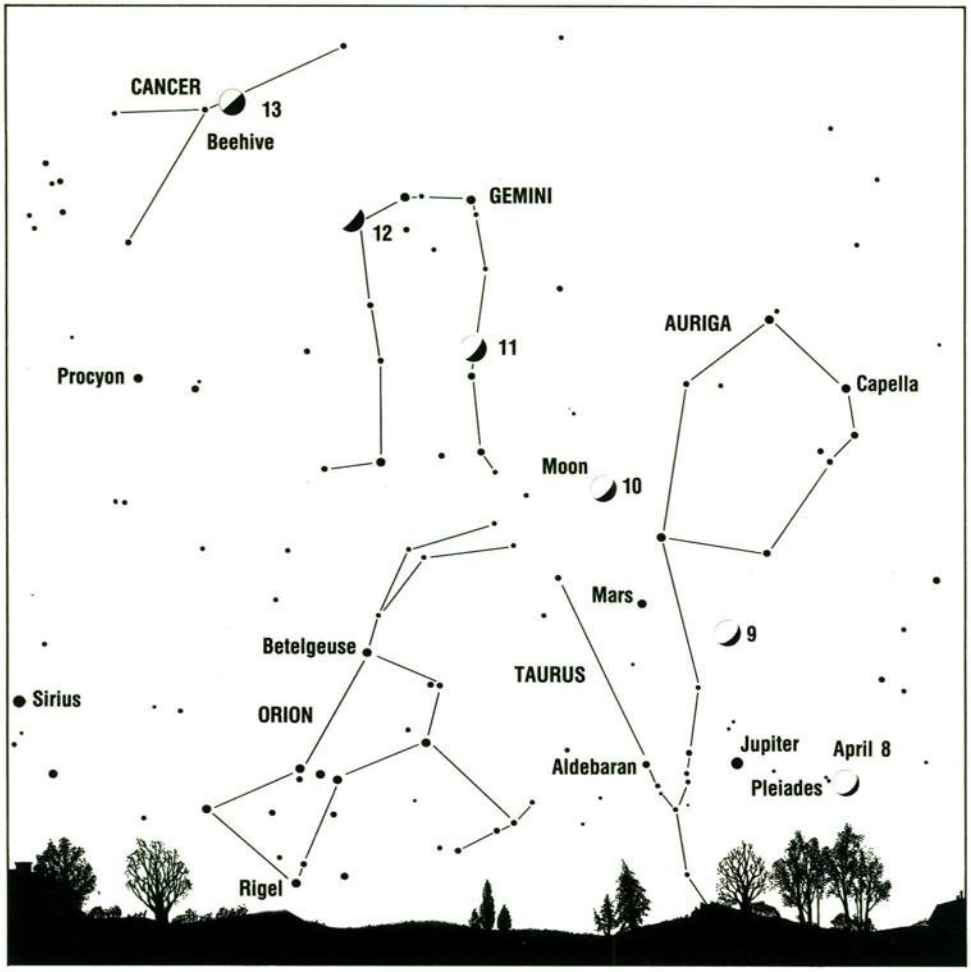
OCCULTATION OF REGULUS

City	Disappears	Reappears
Atlanta	4:58 EDT	5:42 EDT
Austin, TX	—	4:39 CDT
Birmingham, AL	3:56 CDT	4:41 CDT
Charlotte, NC	5:03 EDT	5:46 EDT
Columbia, SC	4:59 EDT	5:44 EDT
Miami	4:47 EDT	5:58 EDT
Nashville	4:06 CDT	4:42 CDT
Tampa	4:48 EDT	5:53 EDT

On the afternoon of April 15, Regulus disappears and reappears from behind the Moon at the times shown. A dash indicates that the event is not visible.



THE PLEIADES ARE OCCULTED by the crescent Moon on April 8. Observers in northeastern North America will see part of the cluster disappear behind the Moon's dark side, the reverse of what Stephen Edberg photographed last June.



FROM THE PLEIADES to the Beehive, the Moon occults two bright star clusters this month. The waxing Moon covers the Seven Sisters on April 8 and then moves through Taurus and Gemini before reaching the Beehive in Cancer on April 13.

Regulus disappear and reappear several times as the star passes behind mountains and valleys along the Moon's north limb. Observers located south of this line can see Regulus pass completely behind the Moon.

Finally, an occultation of Antares, the brightest star in Scorpius, occurs in the Southern Hemisphere early on the morning of April 24. North American observers will be able to see the waning gibbous Moon pass slightly south of the ruddy star.

THE CHANGING FACE OF MERCURY

Mercury, the most Moonlike of the planets, has its best apparition of 1989 in the evening sky of late April and early May. At greatest elongation on April 30, Mercury sets at the end of astronomical twilight, nearly two hours after sunset! You should be able to find Mercury a half to three quarters of an hour after sunset when it is still relatively high in the west-northwest.

The most exciting telescopic observations you can make are of Mercury's changing size and phase. Over the course of just twenty-five days you can watch Mercury nearly double in size while its phase shrinks from gibbous to a slender crescent.

Begin observing the planet after it comes out from the Sun's glare around the middle of the month. On April 15 you will see Mercury's 86 percent-illuminated, 5.6"-diameter disk. Five days later the disk has grown to 6.2" across while the phase has shrunk to 70 percent lit. In five more days, on April 25, the disk measures 6.9" in diameter, but it is now just over half-lit.

On the date of greatest elongation, when Mercury is 21° east of the Sun, the planet's 7.9"-diameter disk is 38 percent lit. Although greatest elongation normally corresponds to a 50 percent-lit phase, the orbit of Mercury is so eccentric that the planet appeared half-lit four days earlier. By May 5, Mercury has ballooned to 9.0" across and appears 24 percent lit. As this evening apparition winds down, Mercury has grown to 10.2" in diameter and possesses a slender, 13 percent-illuminated crescent on May 10.

TELESCOPIC PLANETS

Venus reaches superior conjunction on April 4, which means it is on the far side of the Sun and thus invisible in the night sky. You might be able to find it during daylight in late April using the techniques outlined in February's Through the Eyepiece. If not or if you prefer nighttime observing, Venus begins a long run in the evening sky in May.

High in the west after sunset, Mars is a mere shadow of what it was last year. The Red Planet now shines at magnitude +1.5 and appears as just another bright star in Taurus. The disk of Mars measures a tiny 5" across, so the chances of seeing much surface detail are slim. It is still worth taking a look, however, because the dark markings may pop into view during moments of very steady seeing.

Jupiter continues to dominate the western evening sky throughout

TRANSIT TIMES OF JUPITER'S GREAT RED SPOT

Date	Time
April 2	10:36 p.m.
April 5	12:16 a.m.
April 7	1:55 a.m.
April 7	9:47 p.m.
April 9	11:26 p.m.
April 12	1:05 a.m.
April 12	8:57 p.m.
April 14	10:36 p.m.
April 17	12:16 a.m.
April 19	9:47 p.m.
April 21	11:26 p.m.
April 24	1:05 a.m.
April 24	8:57 p.m.
April 26	10:36 p.m.
April 29	12:16 a.m.

Times are in eastern daylight time. Subtract 1 hour to obtain CDT, 2 hours for MDT, and 3 hours for PDT. The Red Spot is visible for two to three hours before and after a transit.

April, but its days there are numbered. The giant planet — now 34″ across — is sinking lower in the west each day and by next month will be setting during twilight.

When I last saw the Great Red Spot (in mid-December as I was writing this column), it appeared a bit redder than earlier in the fall. The spot was exactly on the meridian, I was using a high-quality 8-inch Newtonian at 155 power, and the seeing was excellent. Good seeing tends to make subtle differences in color or brightness more prominent, so I'd recommend making your own estimates of the Red Spot's color to see if it is changing. Use the table on page 58 to find out when the Red Spot crosses the center of Jupiter's disk.

You can also use the values given in the table to determine the Red Spot's transit times a few weeks before and after those listed. Simply add or subtract multiples of the time it takes the Red Spot to rotate once around Jupiter — 9 hours 55 minutes 51.6 seconds — to the times listed in the table. For example, if you add seven times the Red Spot's period to the last entry in the table — 12:16 a.m. on April 29 — you'll arrive at 9:47 p.m. on May 1, another convenient time to observe. And you can keep adding multiples to build your own table for the following weeks. In the same way you can use the table to figure times back into March by subtracting multiples of the Red Spot's rotation period.

The ringed planet Saturn now dominates the morning sky from its position in Sagittarius. Saturn rises around 1:30 a.m. local daylight time in mid-April and is low in the southeast as twilight begins. As the month progresses Saturn rises earlier and is higher in the sky at dawn.

Golden-colored Saturn shines at magnitude +0.5 and appears 17″ across in your telescope's eyepiece. The rings span 38″ and are still inclined steeply — 25° from our vantage point — so you can get a fine view of this solar system showpiece.

Saturn's neighbors, Uranus and Neptune, also rise earlier and appear higher in the sky as twilight begins this month. Uranus is located nearly 10° west of Saturn and shines at magnitude 5.6. Its 3.7″-diameter, blue-green disk is unmistakable in a telescope's eyepiece. Neptune, less than 2° west of Saturn, is a 7.2-magnitude object with a 2.2″-diameter, bluish grey disk.

ASTEROIDS IN THE EYEPIECE

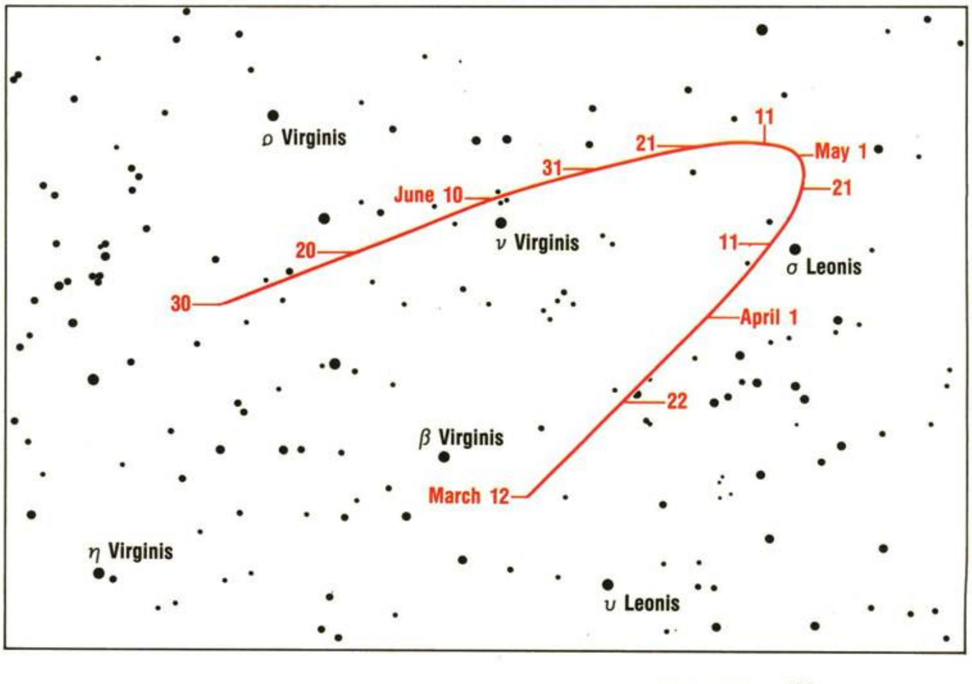
A number of 10th-magnitude or brighter asteroids grace our sky this month. Minor planet 51 Nemausa, which reached opposition on March 15, spends April in Leo and passes less than 1° east of Sigma (σ) Leonis in the middle of the month. Use the finder chart or table of coordinates at right to locate the 10th-magnitude asteroid's approximate position, and then observe that area at low power and sketch or photograph what you see. If you repeat the same observation a night or two later, you'll notice a point of light that has changed position. That's Nemausa.

Other bright asteroids this month include 3 Juno, a 9.5-magnitude point of light located about 5° west of Regulus. Juno can be found with the help of the map in March's Through the Eyepiece. The brightest asteroid in the sky right now is 7th-magnitude 4 Vesta, which reaches a very favorable opposition later in the year. □

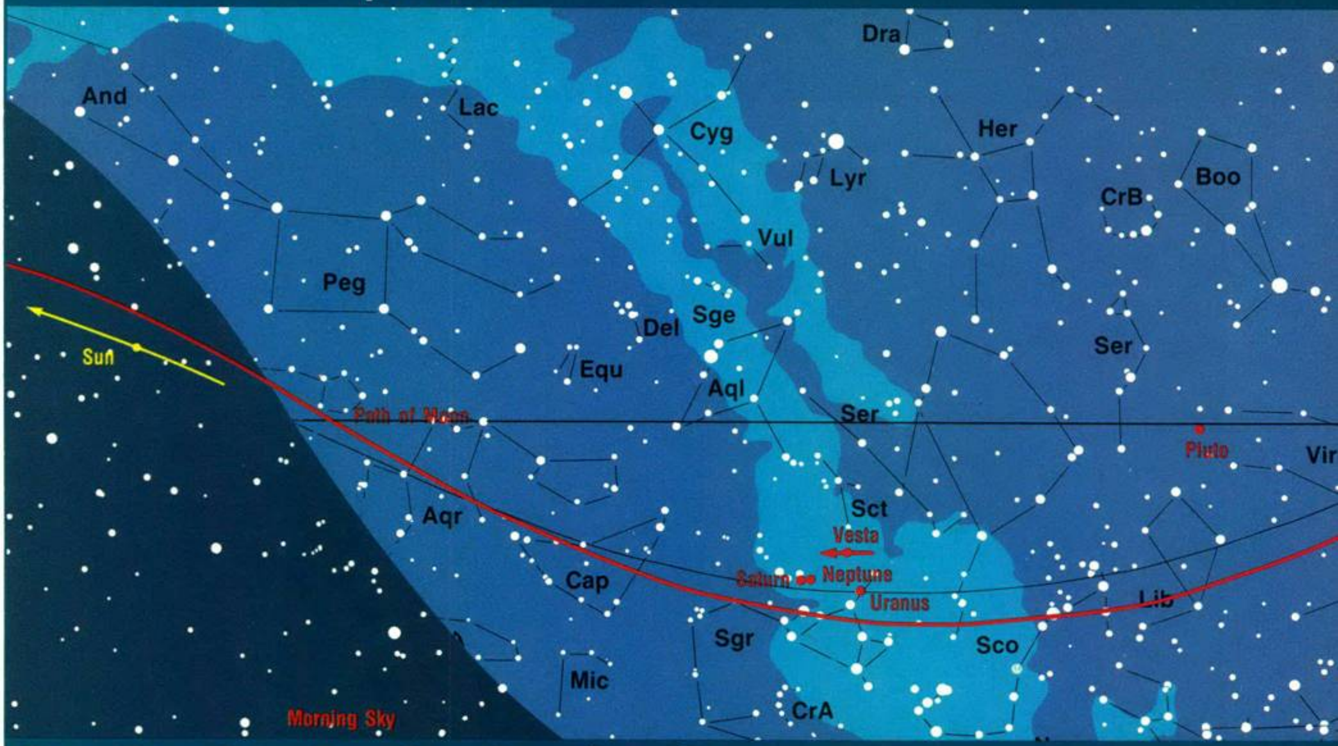
COORDINATES FOR NEMAUSA

Date	R.A. (2000) Dec.
March 12	11h43.6m 0°57′
March 22	11h35.6m 2°52′
April 1	11h28.5m 4°40′
April 11	11h23.2m 6°10′
April 21	11h20.5m 7°16′
May 1	11h20.7m 7°56′
May 11	11h23.7m 8°12′
May 21	11h29.2m 8°04′
May 31	11h36.9m 7°37′
June 10	11h46.5m 6°54′
June 20	11h57.7m 5°57′
June 30	12h10.1m 4°49′

TRACK ASTEROID 51 NEMAUSA through Leo and Virgo in the coming months. The minor planet fades slowly from 10th magnitude after its mid-March opposition. (Positions are given for 0 UT.)



The Solar System April 1989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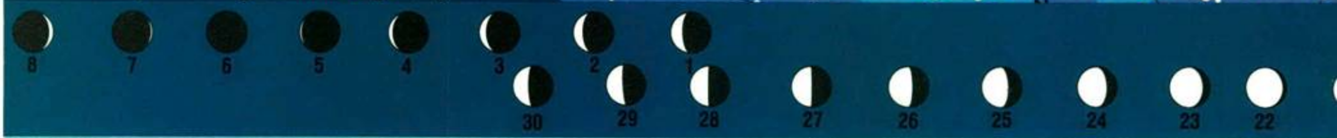
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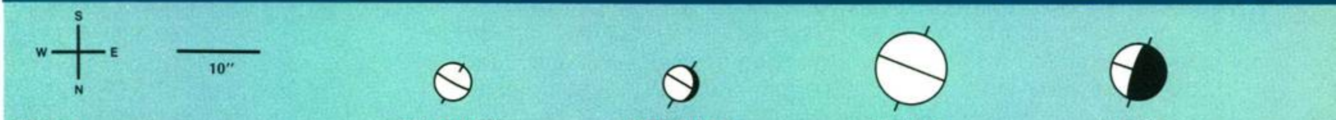
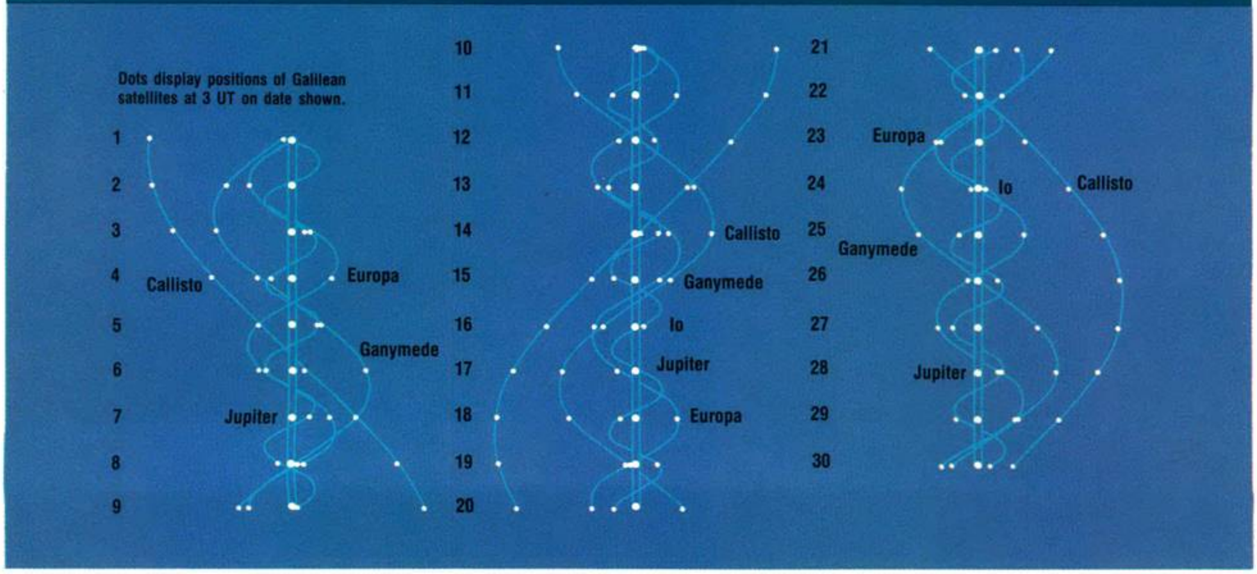
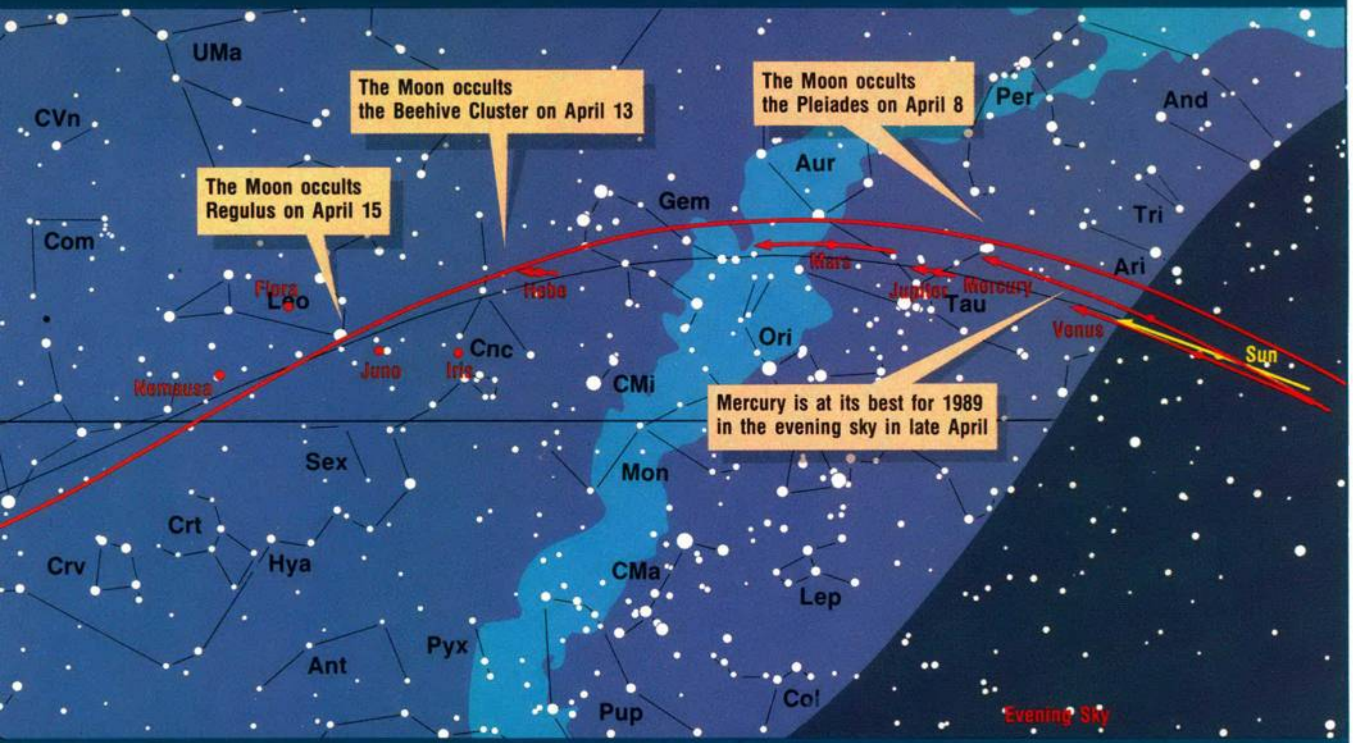


Planet	MERCURY	MERCURY	VENUS	MARS
Date	April 1	April 30	April 15	April 15
Magnitude	−1.6	+0.2	−3.9	+1.5
Angular Size	4.99″	7.68″	9.7″	4.8″
Illumination	99%	41%	100%	93%
Distance (AU) from Earth	1.349.	0.876	1.725	1.946
Distance (AU) from Sun	0.358	0.363	0.724	1.620
Right Ascension (2000.0)	0h30.5m	3h50.2m	1h44.5m	5h22.1m
Declination (2000.0)	1°43′	22°50′	9°43′	24°32′

Jupiter's Moons


Dots display positions of Galilean satellites at 3 UT on date shown.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Nemausa
Juno
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Jupiter
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Sun
Ori
CMi
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Sex
Crt
Crv
Hya
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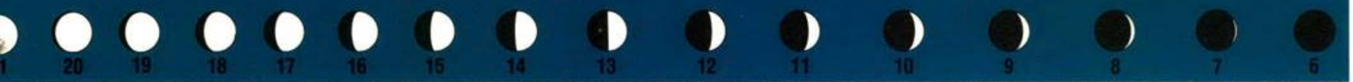
Pyx
CMa
Lep
Pup
Col
Evening Sky

The Moon occults the Beehive Cluster on April 13

The Moon occults the Pleiades on April 8

The Moon occults Regulus on April 15

Mercury is at its best for 1989 in the evening sky in late April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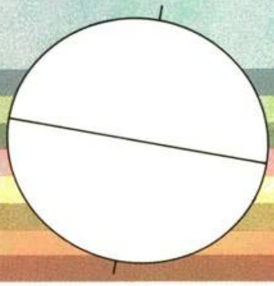
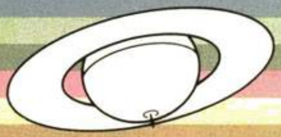
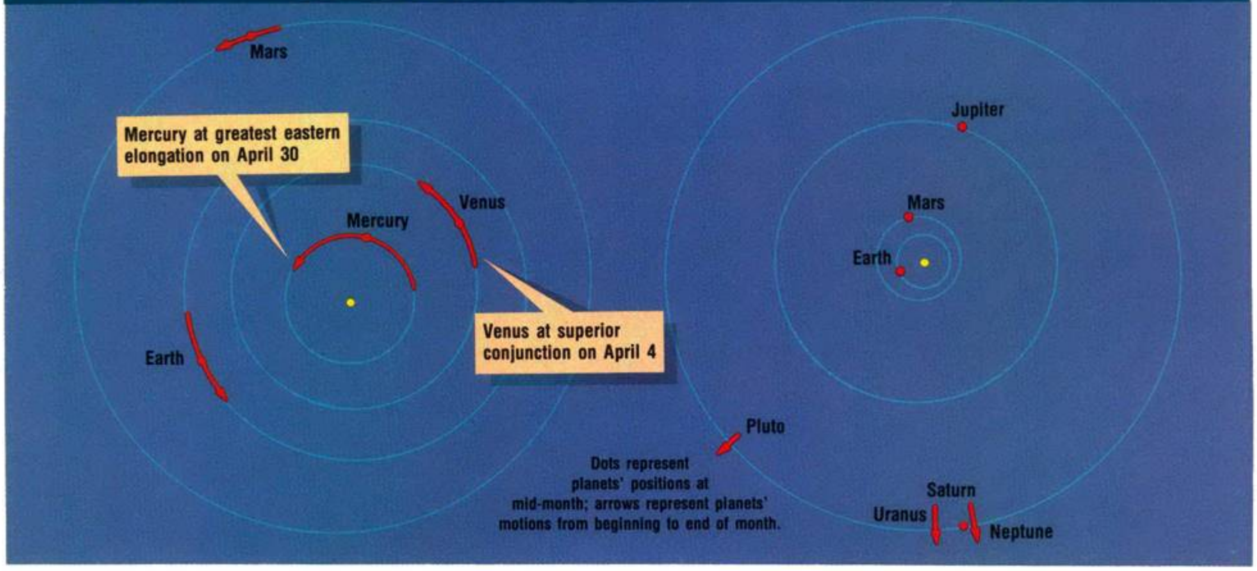




JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
April 15	April 15	April 15	April 15	April 15
−2.0	+0.5	+5.6	+7.9	+13.7
34.1″	16.9″	3.7″	2.2″	0.1″
100%	100%	100%	100%	100%
5.774	9.799	18.972	29.982	28.745
5.062	10.041	19.333	30.217	29.657
4h18.2m	19h00.6m	18h23.9m	18h54.1m	15h07.1m
20°52′	−22°02′	−23°35′	−21°56′	−0°34′

The Planets in Their Orbits


Mars
Mercury
Venus
Earth
Jupiter
Mars
Earth
Pluto
Saturn
Uranus
Neptune

Mercury at greatest eastern elongation on April 30

Venus at superior conjunction on April 4

Dots represent planets' positions at mid-month; arrows represent planets' motions from beginning to end of month.

The New Generation of Dobsonians

Easy to store, transport, set up, and use, the new Dobsonians fit the lifestyle of the amateur astronomer.

by Richard Berry

Dave Kriege rolls a squarish box down a short ramp from his van. He inserts light aluminum tubes into holders, raises a hollow cylinder and snaps it to the tubes, and then slips a cover off the box, revealing a 20-inch mirror inside.

Popping an eyepiece into the focuser, he swings the telescope around and takes a long, satisfying look at Mars, rising in the eastern sky. It's been only ten minutes since he pulled to a stop — and he's already observing with his 20-inch Dobsonian reflector.

Says Kriege, "Evolving Dobsonian technology allowed me to build a big telescope that's a pure delight to use. I spend more time observing now than I ever did when I was younger. My only regret is that I wasted twenty years indoors."

Your future may hold a telescope like Kriege's.

In the decade since the Dobsonian telescope brought large telescopes to amateur astronomy, telescope makers around the world have struggled to improve the original Dobsonian concept — an effort that has paid off for Dave Kriege. Last spring he built one of the first of the new generation of Dobsonian telescopes.

But Kriege is hardly alone. I spoke with Kriege, Pete Smitka, and Ron Ravneberg at Astrofest, held near Kankakee, Illinois, from September 9 to 11, 1988, about the new Dobsonian telescopes they have designed. The techniques these telescope makers have developed are available to everyone and will soon be widespread.

The New Dobsonians

Four features characterize the new Dobsonians. They're extremely portable, they're easy to set up, and they fit the "drive to dark skies" lifestyle of today's observer. In addition, they're capable of excellent optical performance.

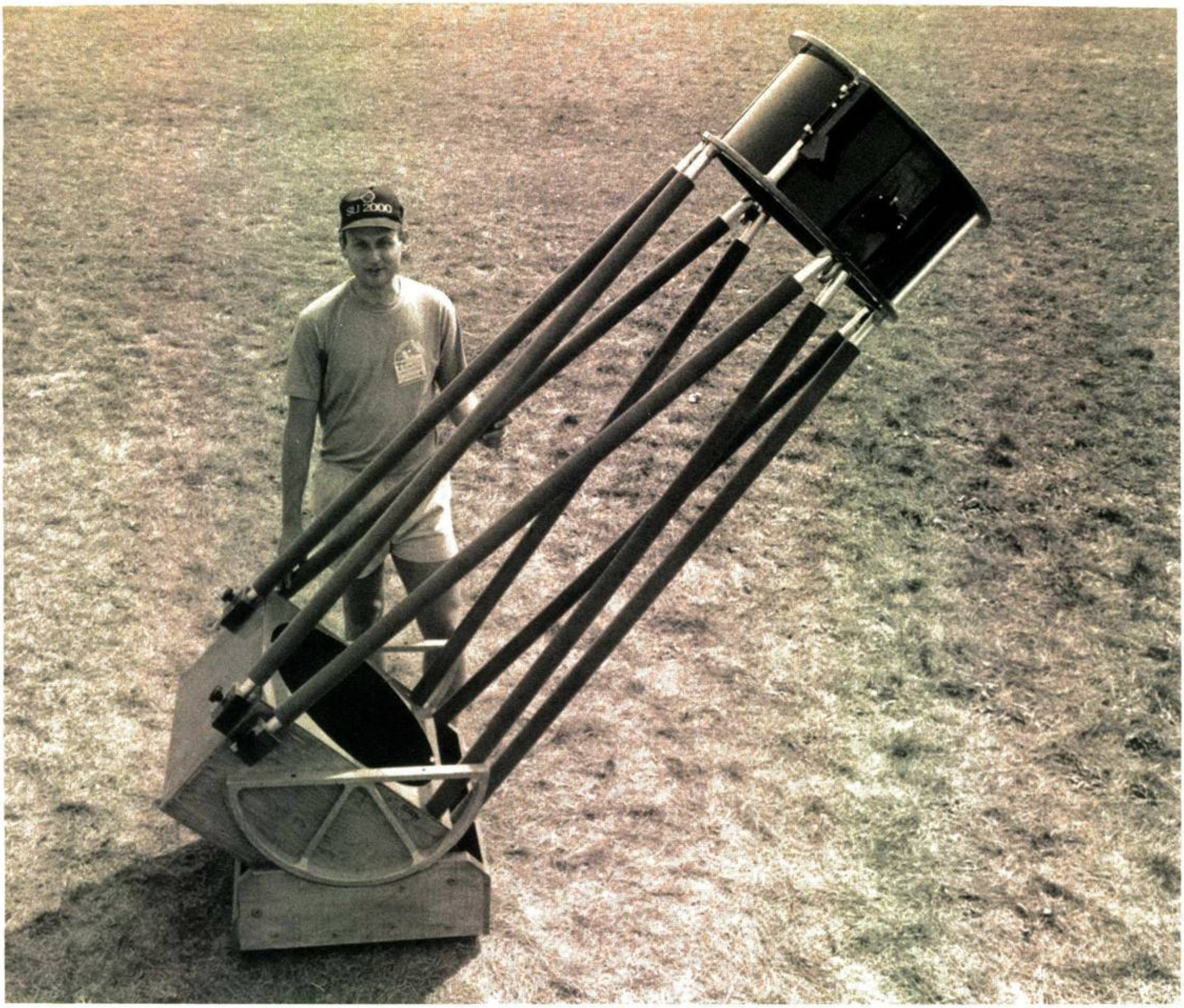
Large telescopes of the original Dobsonian design don't offer the easy portability today's observers want. While retaining the key concept of the original Dobsonian — bearings with enough friction to hold the telescope steady — scores of seasoned telescope builders around the world began to rethink the classic materials and approaches. Thus, new Dobsonians didn't come about by chance: they evolved from the classic Dobsonian.

Portability hasn't always been an important attribute of telescope performance, but the spread of cities and light pollution changed all that. Pete Smitka of New Berlin, Wisconsin, realized that no matter how fine his telescope was, it would be useful only if it was portable. "From the moment I decided to build a 17.5-inch scope," says Smitka, "I knew I had to design it around my ability to transport it to a dark sky."

In telescopes with apertures larger than 14 inches, the tube is the least portable part, followed closely by the telescope's mounting. (For telescopes with apertures smaller than 12 inches, the solid tube still makes good sense.) Two major design goals for a portable telescope were to reduce the size of the tube and to shrink the mounting as far as practical. The obvious solutions are to design a tube that can be disassembled and to build the shortest possible mounting.

"Those big tubes are heavy," tele-

QUICK SCOPE SETUP offered by new Dobsonian designs leaves more time and energy for astronomy. Dave Kriege rolls out his 20-inch telescope, attaches the tube struts, clamps on the upper end — and he's ready to observe!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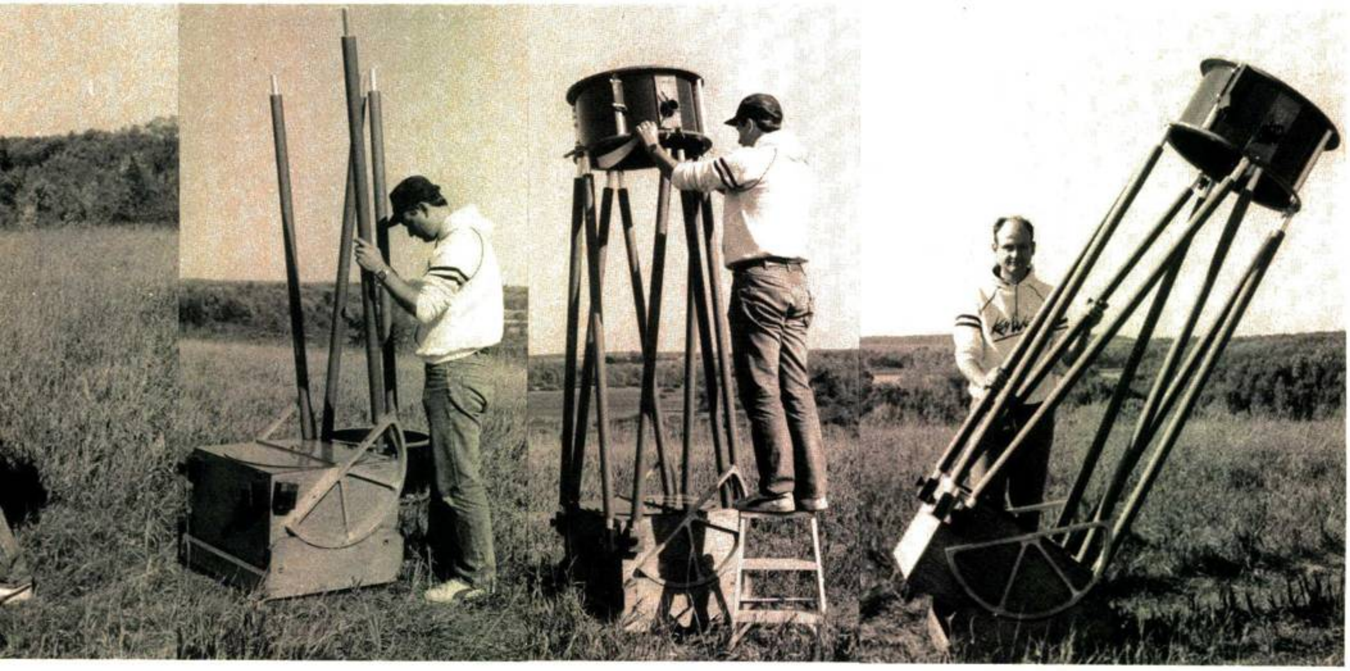
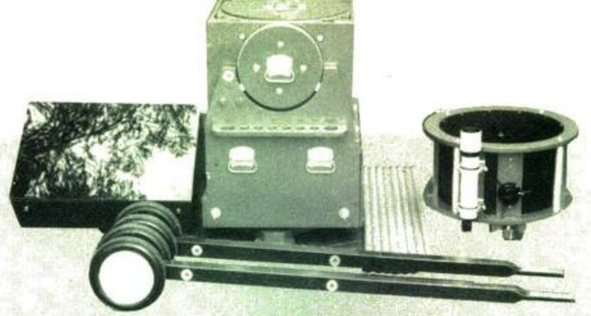
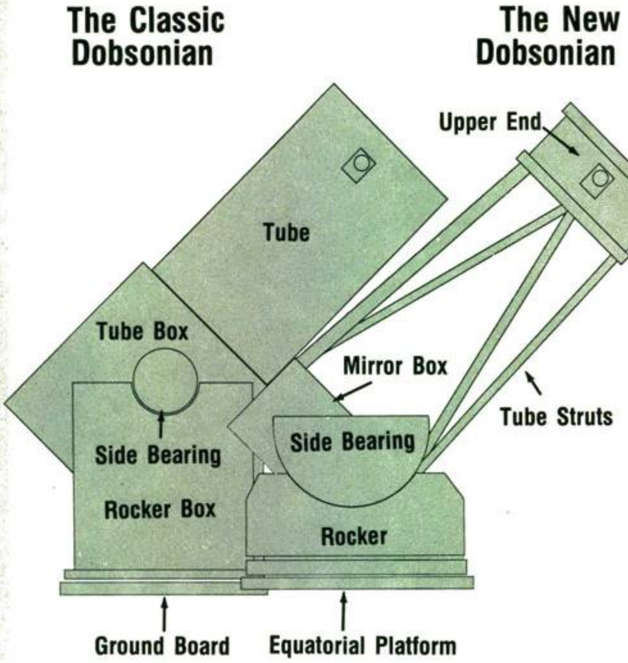


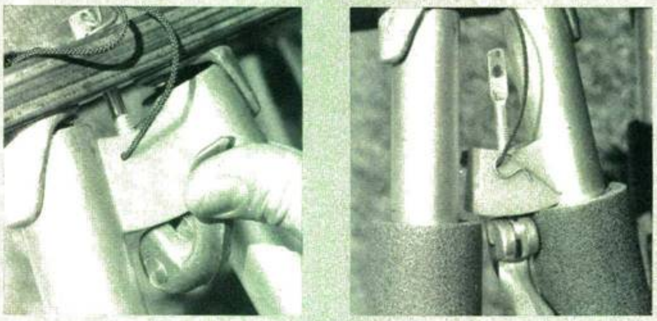
DETAILS MAKE THE DIFFERENCE

The new Dobsonians break down for easy transport to dark-sky observing sites, and clamps make reassembly quick and hassle-free. The lightweight upper end, low-profile mirror box and rocker, and large-diameter bearings make the difference.

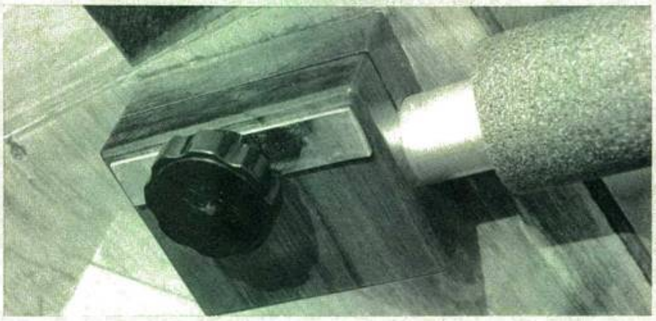


Bolt-on wheels and modular construction make Ron Ravneberg's 17.5-inch reflector easy to roll out for observing.





The upper end of Dave Kriege's 20-inch telescope is held in place by a wedge and a clamp that takes seconds to snap tight.



Clamp blocks grip the light aluminum struts that support the light upper end of Kriege's new Dobsonian telescope.

scope builders reasoned. "Let's replace the center section with struts. That'll also eliminate tube currents, and let the optics cool rapidly." The open-tube concept, first put into practice by Swedish amateur Ivar Hamberg, worked beautifully. It was soon copied around the globe.

Because the open tube weighed less, the telescope's balance point moved closer to the bottom of the tube. This meant that less of the mirror box stuck out behind the bearings, so the bearings could be closer to the ground and would require a lower rocker box.

But taking the telescope apart in order to transport it to an observing site means putting it back together *again at the site.* We've all felt sorry for some poor soul we saw at a star party struggling to assemble a telescope, dropping bolts and washers on the ground while juggling a flashlight, two screwdrivers, and a handful of hex wrenches. They wanted portability but not hassles. "I wanted a design that would go together in under five minutes," says Ron Ravneberg of Columbus, Ohio.

Ravneberg solved the problem by holding the struts with homebuilt wood clamps. Kriege saw the clamps at the 1987 Astrofest meeting, and a year later showed his own improved clamp design. When telescope makers built telescopes, they showed them to other telescope makers and kept their eyes open for new ideas. Thus the new Dobsonian evolved.

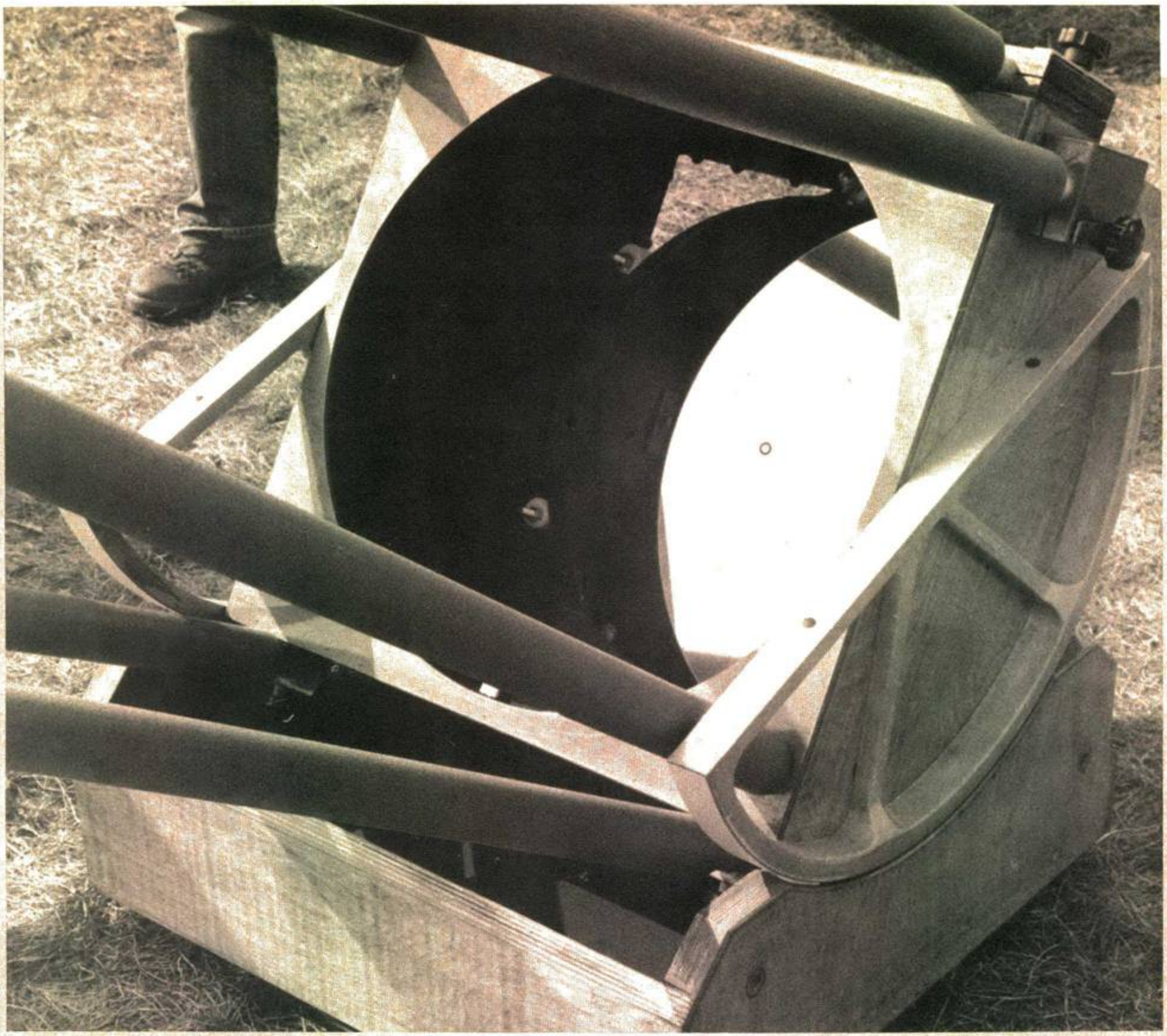
Think 'Observing System'

Pete Smitka didn't build a telescope; instead he built an "observing system." "The key to using a large telescope," says Smitka, "is to think of it as only one part of a system that includes storage, transport, and observing site." Every element in the system is important because every element has to function effectively before you can observe with the telescope.

Even the most portable telescope is no good unless the transport part of the system works too. Smitka decided to modify a small trailer to carry his telescope. "The trailer keeps all the components of my telescope in one place and has the added advantage of being ready to use on short notice." In addition, the trailer gives him a place to store the telescope when it's not in use.

The "system" approach extends to details of telescope use too, such as electric power availability and keeping eyepieces dry, dew off the finder, and star charts ready at hand. In the new Dobsonians these important details become a part of the system, just as the telescope is a part of the system.

Within the telescope itself, the most important part is the optical system, the mirrors that collect starlight and form an image. Good telescope per-



Air flows freely around the 20-inch primary mirror so it cools rapidly to air temperature and gives sharp images.

formance requires good mirrors, good mirror mounts, and good seeing. Most mirrors for large Dobsonians come from optical shops that specialize in making large optics at prices that are typically one fourth the cost of comparable professional optics. The key is that you can't buy the really good mirrors at bargain prices — there's simply too little profit margin to allow the time-consuming testing and figuring required.

For the new Dobsonians, telescope makers are spending more on the optics and expecting more from them. One route is to buy a bargain-price mirror and have an expert optician refigure it to one-tenth wave or better. Another route is to buy the mirrors from a firm with a reputation for making good optics — Dave Kriege recommends Galaxy Optics of Boulder, Colorado — and then pay the higher price. Ron Ravneberg had his mirror refigured, and Pete Smitka had to return his mirror to the shop that made it before getting a mirror good enough to use.

Given good optics, the new open-tube designs perform better than closed-tube telescopes because the mirrors cool to air temperature much faster and the open tube doesn't harbor image-harming currents of warm air. The result is that viewing is limited only by atmospheric turbulence and not by problems in the telescope.

What's in a Design?

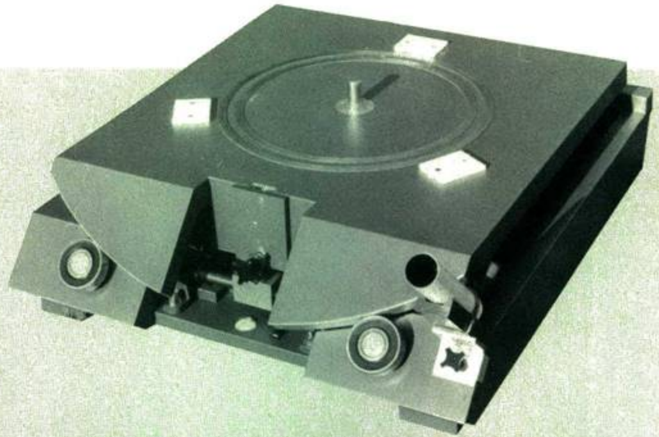
One of the keys to the new Dobsonian telescope is the light-weight upper end. Because it serves only to hold a diagonal mirror and an eyepiece out in front of the primary mirror, Kreige reduced the upper end of his telescope to two wooden rings joined by lengths of aluminum tubing.

"Minimizing upper-end weight is half the secret to the short-profile rocker base," says Kriege. Instead of a heavy tube wall, Kriege used a sheet of 0.010-inch-thick Mylar plastic, painted black, that weighed mere ounces to block light. He also dispensed with bolts and fasteners and used epoxy glue to hold the parts together. The upper-end assembly of Kriege's telescope, including the focuser and secondary, weighs only ten pounds.

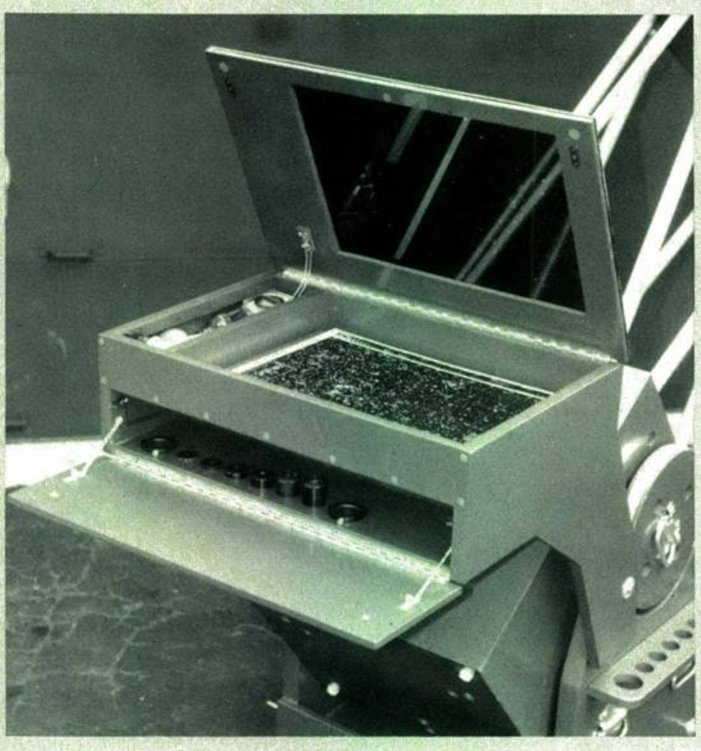
"Struts are the central element in the transportability equation," claims Smitka, "because they make a light and rigid support for the upper end." The struts also eliminate the need to transport a bulky and heavy section of telescope tube to the observing site. But struts pose problems that telescope makers solved only with the new Dobsonian. Struts have to be attached tightly to the mirror box and the upper end, but for the sake of portability the struts must be easy to assemble. Lots of people built telescopes with bolts to hold struts in

SYSTEM THINKING

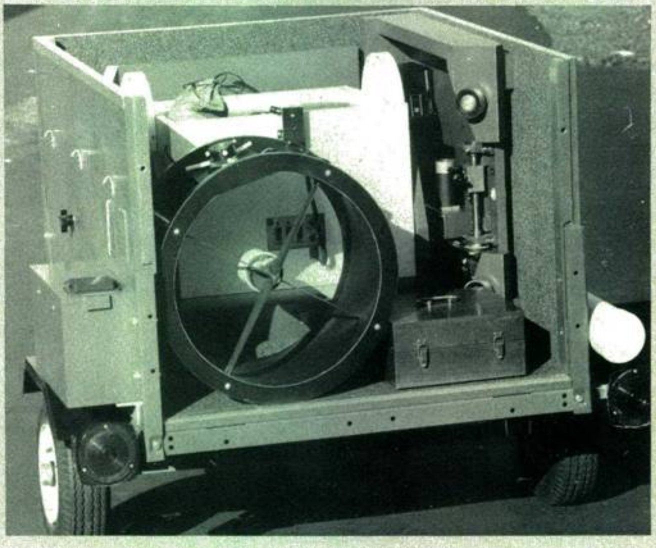
Transport, tracking, charts, and finder — as well as the telescope — are all parts of an "observing system." When each element in the system functions well, the whole system provides a first-rate observing experience.



To follow the stars, Pete Smitka's Dobsonian rides on a tracking platform that serves as its equatorial mounting.



Charts, eyepieces, and books stay dry in Ron Ravneberg's handy behind-the-telescope observing table.



Always ready to go, this little trailer lets Smitka hitch up and drive his telescope to dark skies whenever he wants.

place, but it was a cumbersome solution at best and wobbly at its worst.

Ravneberg attacked the strut problem with the aid of his friend Bob Scholtz. "Bob and I tried everything we could think of," reports Ravneberg, "before it occurred to us to switch from fasteners to pressure clamps." By inserting the tube into a split block of wood, the builders achieved a tight, wobble-free grip on the tube.

At the upper end Ravneberg fashioned tube grippers from handmade wooden wedges held in place by bolts. After seeing Ravneberg's telescope, Kriege hit on canoe-rack clamps for locking the wedges in place, and because he's a dentist, he cast the wedges in dental acrylic plastic.

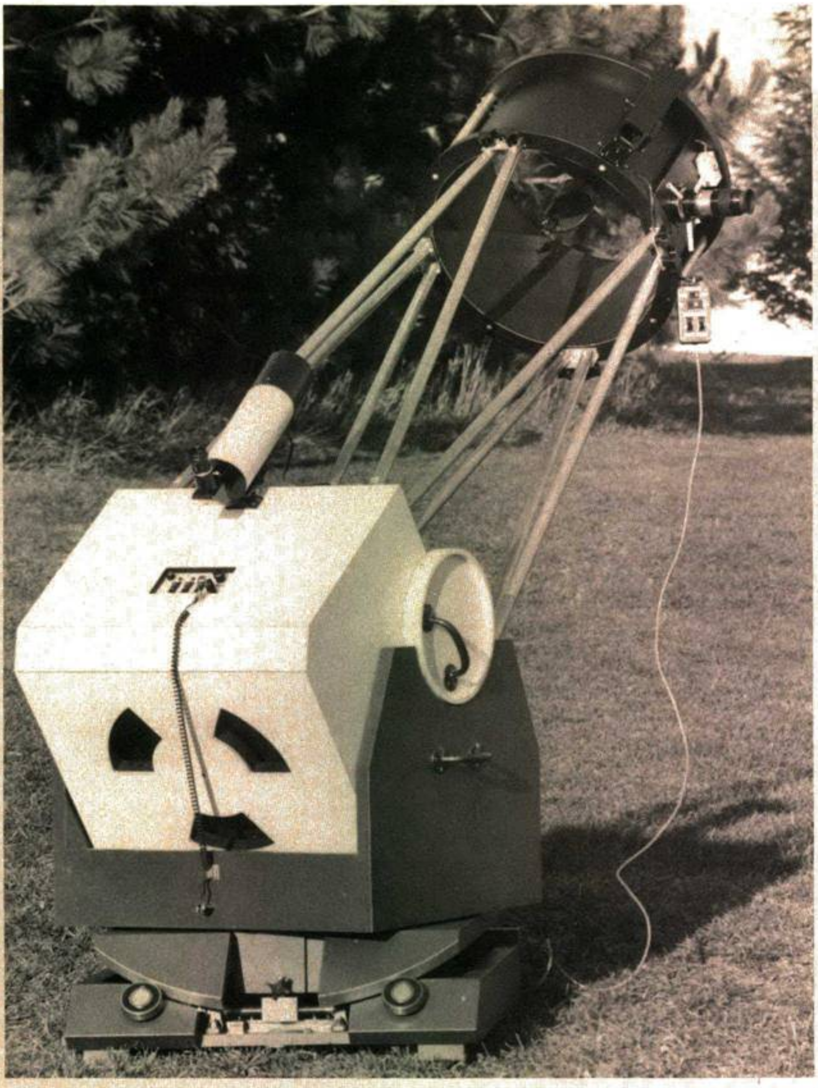
Good bearings for a Dobsonian depend on materials and geometry. Bigger bearings mean a lower rocker box and greater stability — two desirables. But size has its drawbacks too. The bigger the bearings, the harder the telescope moves. Although the classic Dobsonian bearing is Formica laminate plastic riding on Teflon plastic, no one knew exactly what kind of Formica and Teflon would give the characteristic "buttery" feel and easy motion of the best Dobsonians.

When Kriege decided to build his telescope, he decided to experiment with different kinds of Formica and Teflon and discovered that #7181 tweed-textured Formica and "virgin" Teflon give smoother motion and lower friction than any other combination he tested. The low friction allowed Kriege to use a side bearing 26 inches in diameter and a very stubby rocker box.

Every time you have to dig around in your toolbox for an Allen wrench, you're wasting time, according to Ravneberg. "As much as possible I wanted to avoid loose parts during assembly. They invariably get lost. That ruled out using extra bolts, washers, wing nuts, or special tools." Ravneberg designed every component of his telescope for ⅜-inch machine bolts, from the clamps that hold the tube struts to the collimation bolts behind the mirror. Kriege went a step farther. He used knurled knobs and clamps to lock struts in place, which speeded up setup and eliminated the need for tools.

Essential Frills

If the telescope really is just one part of the observing system, it won't be effective unless the other parts of the system are also fine-tuned for nightly use. "I knew that if my telescope wasn't fun to operate," Kriege attests, "I would probably end up watching TV instead of the sky." Storing star charts, keeping dew off the optics, lugging the telescope, tracking stars, and getting the telescope to the observing site all rank high when it



Just a little bit of electric heat banishes dew from Smitka's diagonal mirror, finder, and eyepieces.

comes to making nights under the stars worthwhile.

Observing can be a disaster when there's too much loading and lugging to do. Pete Smitka solved the hefting and hauling problem with a small trailer. "All I have to do is dress for the weather, hitch on the trailer, and go," he reports. "The trailer satisfies my need to have a large telescope ready to take to a dark site without a lot of fuss." Smitka unloads his trailer at his favorite observing site and he's ready to observe in minutes.

Kriege carries his telescope in a van and puts up with loading and unloading the telescope for each observing trip. However, he's eliminated much of the exertion. He sets two wood ramps in the van door, bolts wheelbarrow-type handles to the 150-pound rocker and mirror boxes, and then rolls them out of the van.

Juggling star charts, eyepieces, and flashlights was once a problem for observers — but no longer. "No matter where I point the telescope," claims Ravneberg, "my observing table is always in exactly the same location relative to the eyepiece." The convenience means easier observing with less fumbling in the dark.

The table attaches to the rocker box of the telescope and contains virtually everything Ravneberg needs for observing. It has storage space for eyepieces and filters, an area set aside for tools and flashlights, and a chart box for Tirion's *Sky Atlas* and *Uranometria 2000.0*. Although the table weighs forty pounds and requires a sixty-pound counterweight, his telescope handles the added load easily.

The top surface of the table is made of dark red plastic; directly under the plastic is the space for charts and atlases. By shining a flashlight through the plastic, the observer can read the charts. Because the table is kept closed, it keeps everything inside free of frost or dew.

As dew creeps across exposed optical parts, many a night's observing has ended in soggy frustration. Yet all it takes to beat dew is a few watts of strategically placed heat to keep eyepieces, finders, and diagonal mirrors dry on nights that shut down most telescopes.

Pete Smitka solved his system's dew problems with lengths of nichrome heat tape behind the diagonal, inside the finder, and wrapped around the eyepiece holder. "Dew and frost on my optics are a thing of the past," Smitka maintains, "even in the most extreme conditions." Although heaters are nothing new, on Pete Smitka's telescope they're a permanent part of his telescope and observing system.

Equatorial tracking platforms offer a major extension of the Dobsonian telescope's capabilities. By turning the upper part of the 6-inch-high platform with a small motor, the platform counters the rotational motion of Earth. Thus, for a slight penalty in the telescope's height, a platform lets a large Dobsonian track like an equatorial.

Smitka finds the platform makes his telescope more suitable for star parties ("it eliminates the task of centering the object for a succession of observers"), and tracking is a convenience for all types of observing.

New Tools for Observers

The new Dobsonian will spread rapidly throughout the world of amateur astronomy, much as the original Dobsonian design spread a decade ago. It will spread fastest among amateur telescope makers because they're always looking for an excuse to build another telescope.

"Possibly the best part about building your own telescope," says Ravneberg, "is that you can incorporate the things you prefer into it. When I designed mine, I recognized that it was, in fact, my telescope and should be built for my needs."

But the new Dobsonians probably won't remain only in the hands of inventive amateur telescope builders for long. One company — Sky Designs — already makes kits for an open-tube Dobsonian with bolt-in-place struts. Other companies are likely to follow suit with kits that reduce the need for the workshop skills Kriege, Ravneberg, and Smitka brought to their telescope projects.

The net result is that amateur astronomy will benefit, perhaps enormously. With large-aperture telescopes made lighter, easier to assemble, and easier to transport to dark skies, more people will experience the night sky and come to know the wonders of astronomy. ☐

The Art of Observing Planetaries

The strategy for observing planetary nebulae is to search with low magnification and then switch to higher magnifications to see details.

by David J. Eicher

Planetary nebulae are a pleasant contradiction. Their fuzzy disks are physically similar but appear diverse in the eyepiece, which gives observers a nice variety of shapes, sizes, and brightnesses. Because these objects are spread throughout the Galaxy, some planetaries are easy to see with small telescopes. Others, however, challenge the largest, most sophisticated backyard instruments.

The end of a star's life, a planetary nebula is a shell of gas gently expelled from a star after it exhausts its fuel supply. Planetary nebulae are transitory objects: they slowly expand over the course of about 10,000 years before thinning imperceptibly into the surrounding space. All that is left is a dim, dwarf central star that slowly burns out like a glowing ember. However, only stars of average mass — including our Sun — will become planetary nebulae. Massive stars end their lives explosively as supernovae; tiny stars simply cool off.

One of the most challenging planetary nebulae for small scopes is **M97** (NGC 3587) in Ursa Major. M97 measures slightly over 3′ across and has a brightness of magnitude 12.0. Because its dim light is spread over a fairly large area, M97 has a notoriously low surface brightness. This planetary nebula is much harder to see than the statistics suggest. In fact, most observers place M97 among the most challenging of all the Messier objects. Because of two dark areas that look like eyes on the surface of its disk, M97 is popularly known as the Owl Nebula.

Fortunately M97's location is easy to find. Start by aiming your finder scope toward Merak (Beta [β] Ursae Majoris), the southwestern star in the bowl of the Big Dipper. Swing your finder slightly over 2° southeast and you will come upon a pair of bright stars aligned north-south. The Owl Nebula lies 20′ northeast of the solitary 6th-magnitude southern star.

Challenging Springtime Planetaries

Object	**R.A. (2000.0) Dec.**	**Mag.**	**Size**	***Tirion***	***Uranometria***
NGC 3132	10h07.7m −40°26′	8.2p	>47″	20	II: 399
NGC 3242	10h24.8m −18°38′	8.6p	16″/1250″	13, 20	II: 325
M97	11h14.8m +55°01′	12.0p	194″	2	I: 46
NGC 4361	12h24.5m −18°48′	10.3p	45″/110″	14, 21	II: 328
NGC 6210	16h44.5m +23°49′	9.3p	>14″	8	I: 156

Object: Designation in Messier or NGC catalog. **R.A. and Dec.:** Right ascension and declination in equinox 2000.0. **Mag.:** Photographic magnitude. **Size:** Diameter in arcseconds. ***Tirion:*** Chart on which object appears in *Sky Atlas 2000.0* by Wil Tirion. ***Uranometria:*** Chart on which object appears in *Uranometria 2000.0* by Wil Tirion, Barry Rappaport, and George Lovi.

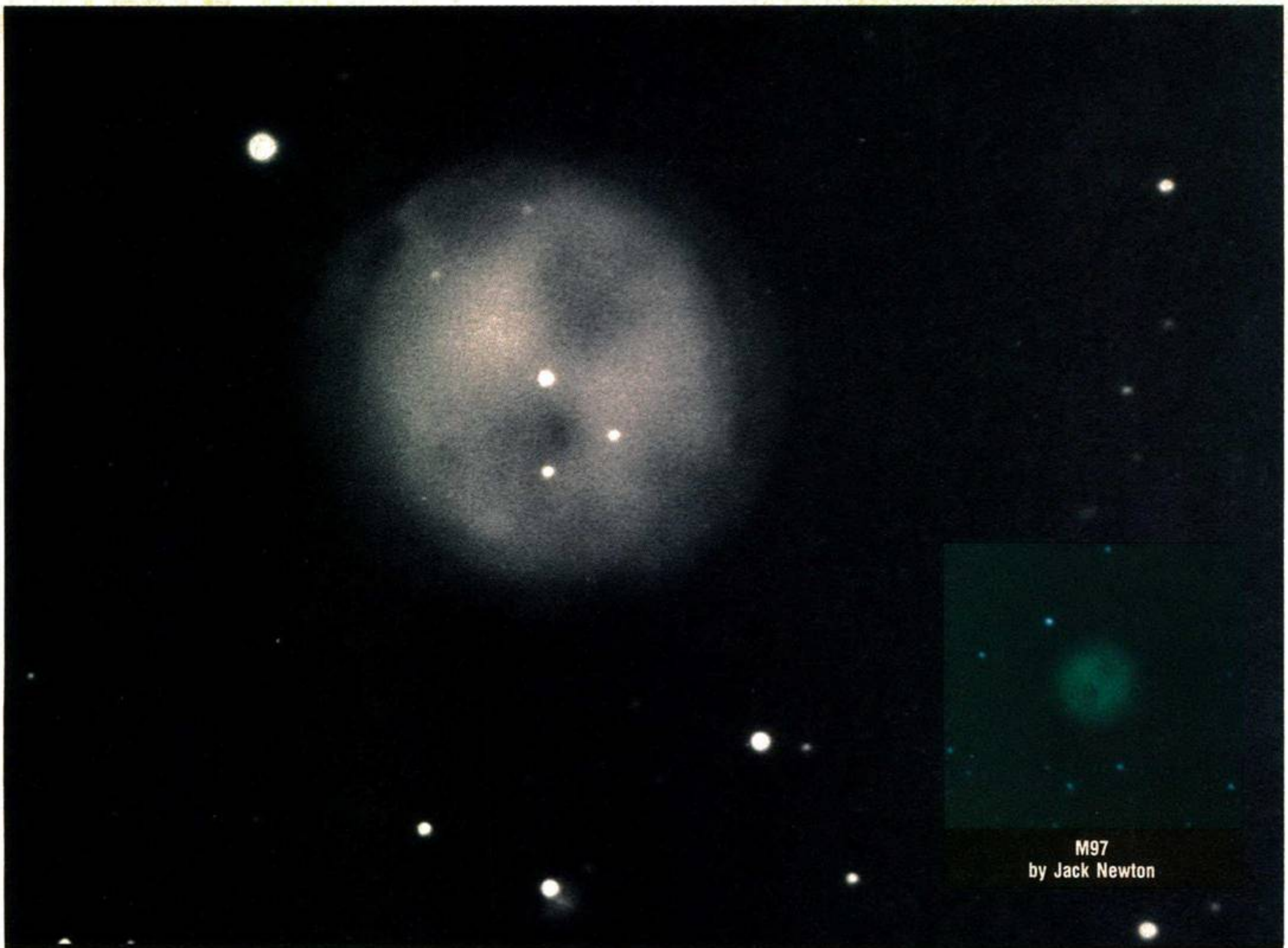
Once you've located M97, what you'll see depends on the telescope you're using. A 3-inch scope is capable of showing the Owl as a tiny, misty spot of gray light but only at high magnifications on exceptionally transparent nights.

With their greater light-gathering power and correspondingly smaller fields of view, 6-inch and 8-inch scopes show a much brighter Owl Nebula. In an 8-inch scope at 170x the Owl looks like a 3′-diameter gray-green patch of light that is perfectly round and almost imperceptibly dimmer toward its edges. The field is strewn with faint stars invisible to smaller scopes, six of which form a distinctive semicircle around the Owl Nebula. This little feature is visible as a line of stars originating south of the nebula and circling clockwise to the brightest star, which lies just north of the Owl.

Ten-inch or larger scopes coupled with steady seeing present two curious features of the Owl. Using averted vision — glancing off to the side of the field — you will see the 12th-magnitude central star embedded squarely in the nebula's center. This tiny dot of light is responsible for shedding the layers of gas that formed the nebula. In addition, a 10-inch scope and averted vision show the two dark patches that gave rise to the nebula's popular name.

Two observing techniques will dramatically improve the detail you can see in planetary nebulae. First, gently moving the telescope in right ascension or declination by small amounts as you use averted vision makes it easier to see minute details. This is because your eyes are greatly sensitive to motion. Second, try using a red-transmissive nebula filter like the UHC filter made by Lumicon. This device transmits the nebula's light to your eye but blocks scattered terrestrial lighting. Using a nebula filter is particularly effective for spotting details like the Owl's eyes.

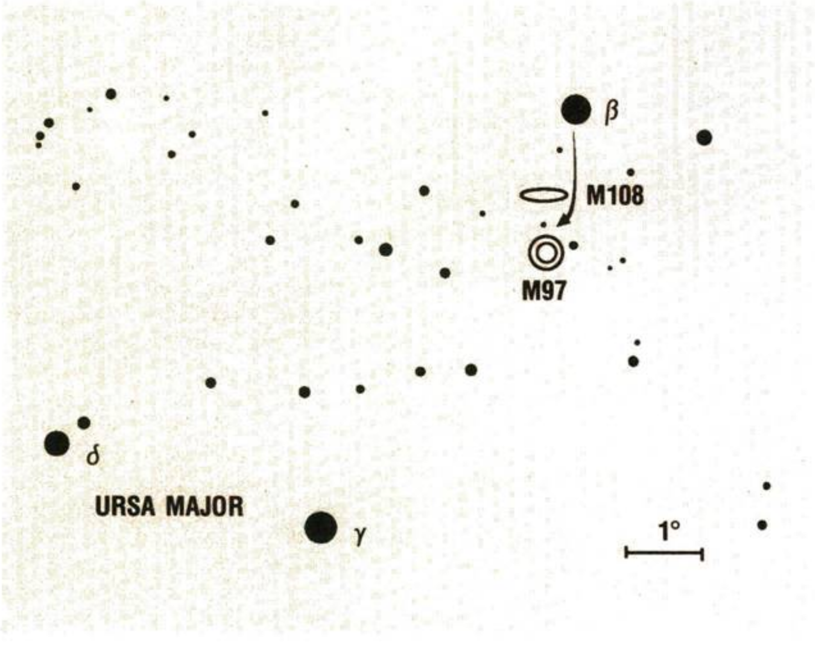
Southern Hemisphere observers have a nicely detailed planetary nebula in **NGC 3132**. Located in the constellation Vela at −40° declination, this planetary is invisible north of +50° latitude. Those who can observe Vela will find NGC 3132 by aiming a finder scope toward the 4th-magnitude star q Velorum, moving 2°



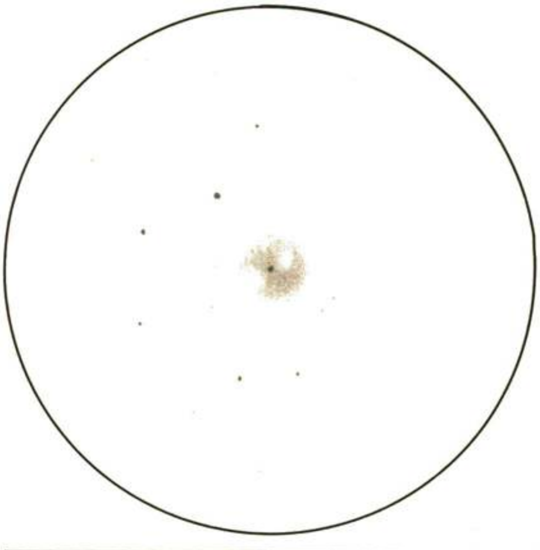
M97
by Jack Newton

M97
Magnitude 12.0 Size >194″ by Jack Marling

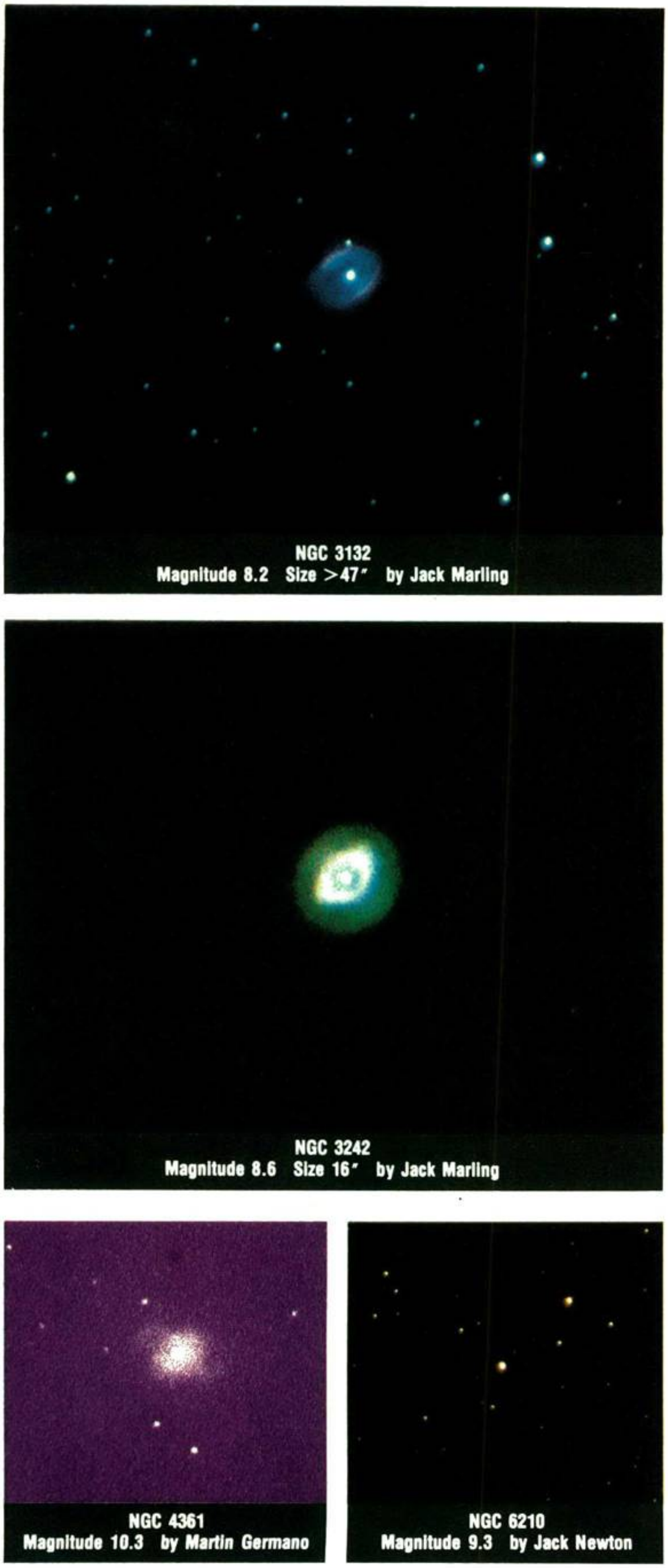
DARK, SPOOKY EYES gaze toward Earth from the Owl Nebula in Ursa Major. The remnants of gas expelled by a star that died suddenly, the Owl Nebula shows a planetary nebula's characteristic strong blue-green color.



FIND THE OWL NEBULA by aiming your finder scope at the bright star Beta Ursae Majoris and then move the scope 2° southeast, past galaxy M108, to the Owl.



M97
8-inch f/10 SCT 100x by David J. Eicher


NGC 3132
Magnitude 8.2 Size >47″ by Jack Marling

NGC 3242
Magnitude 8.6 Size 16″ by Jack Marling

NGC 4361
Magnitude 10.3 by Martin Germano

NGC 6210
Magnitude 9.3 by Jack Newton

RINGS, SPHERES, AND BLOBS are all shapes commonly displayed by planetary nebulae. Vela's NGC 3132 (top) is an easily visible ring. NGC 3242 in Hydra (center) has a complex, multilayered structure. NGC 4361 in Corvus (bottom left) displays a curious, disorganized appearance. Tiny NGC 6210 in Hercules is so small that it's often mistaken for a star.

north to two 6th-magnitude stars, and sliding 1.5° west.

Whereas M97 is round and has an elusive central star, NGC 3132 is a bright, ring-shaped nebula with a 10th-magnitude central star. Even a 2-inch telescope at high power shows the 8th-magnitude nebula measuring 30″ across with its impossible-to-miss central star. With a careful eye and a 4-inch scope you'll see the planetary's ring shape. An 8-inch telescope equipped with a nebula filter shows that the outer edges of the ring, spanning almost 50″, are clearly brighter than the ring's inner parts.

Twenty-two degrees north and slightly east of NGC 3132 lies another large planetary, **NGC 3242**. This object is much more accessible to Northern Hemisphere viewers because it lies 22° higher in the sky. To zero in on this object, start at 4th-magnitude Mu (μ) Hydrae and move your scope 2° south. The nebula lies within the same low-power field as an 8th-magnitude star.

NGC 3242 is a complex object consisting of a bright oval disk surrounded by a much larger, fainter halo of gray-green light. Because of its size, color, and slightly flattened shape, early observers dubbed NGC 3242 the "Ghost of Jupiter." A 6-inch scope shows the bright, flattened oval of nebulosity surrounding a dark central hole. Averted vision reveals the low surface brightness halo of gray-green nebulosity. A 12-inch scope with a nebula filter unveils the 12th-magnitude central star and shows several overlapping layers of increasing brightness, which gives the nebula an almost three-dimensional appearance.

The curious planetary **NGC 4361** lies inside the trapezoid of bright stars that forms Corvus. This nebula shows an unusual bright disk surrounded by an irregularly shaped halo that appears as if it were twisted. Large scopes reveal this faint, curious feature.

To find NGC 4361, aim your scope at Gamma (γ) Corvi (the northwest star in the trapezoid) and swing it southeast by 2.5°. You'll see a pair of 7th-magnitude stars oriented north-south; the nebula lies 30′ northeast of the northern star.

The most obvious feature of NGC 4361 is its large size. If you're in the right place, you'll see a patch of fuzzy light. A 6-inch scope shows a 25″-diameter oval-shaped patch of light with two faint wisps on opposite sides extending to 45″. Larger telescopes reveal the nebula's 13th-magnitude central star and show a relatively strong greenish color in the nebula's brightest parts, all set in a field sparsely splattered with stars.

The bright green nebula **NGC 6210** in Hercules epitomizes every tiny, difficult-to-identify planetary nebula. Located 3° northeast of Beta Herculis, tucked away beside two stars of equal brightness, NGC 6210 measures only 14″ across. Unlike the Owl Nebula (and the other nebulae we've surveyed), NGC 6210 is identifiable as a planetary only because it is green and appears slightly fuzzier than the stars that surround it.

If we could travel to the Owl Nebula, the Ghost of Jupiter, and NGC 6210, we would find that nearly all are the same size. Yet because they lie at different distances, their telescopic appearances vary dramatically — from large and faint M97 to small and bright NGC 6210. Backyard telescopes and patient eyes also show that these objects vary considerably in structure, from rings to disks to complex, overlapping shells. You'll find planetary nebulae to be some of the most varied, unusual forms in the Galaxy. ☐

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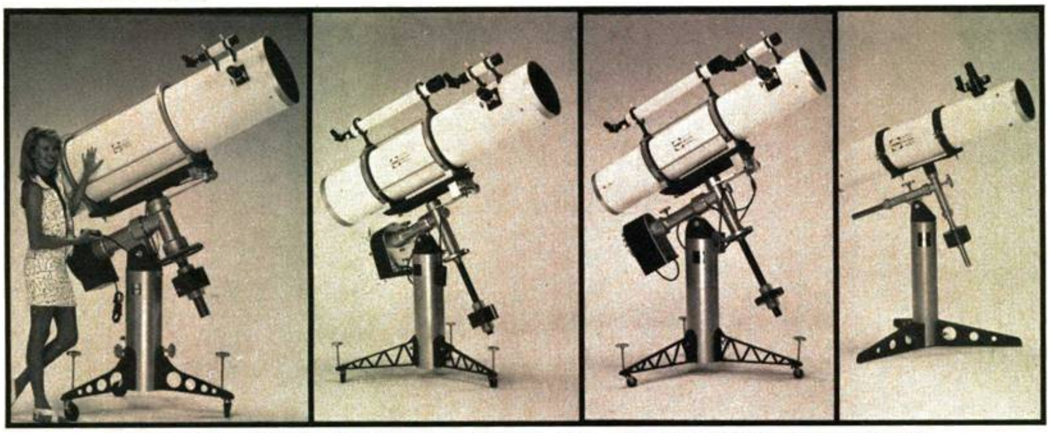

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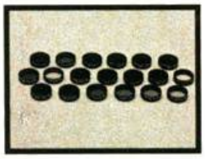

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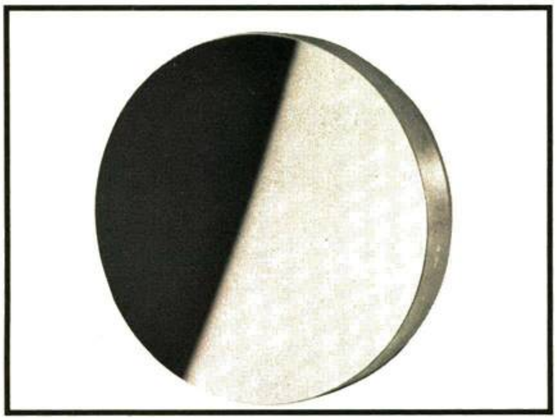

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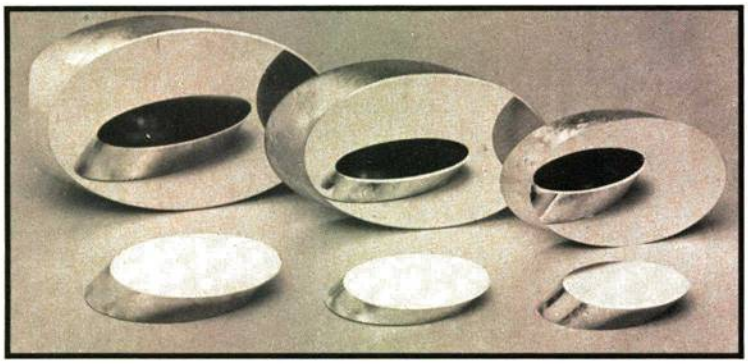

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The "Flame Nebula" NGC 2024 in Orion. Also known as the "Christmas Tree" or the "Tank Trucks" nebula. NGC 2024 is seen best usually with either a LUMICON DEEP-SKY or UHC filter. Photo by Don N. Reiners, 16" f/5, 40 min. using hypered 2415 film and a LUMICON 2" EASY-GUIDER.

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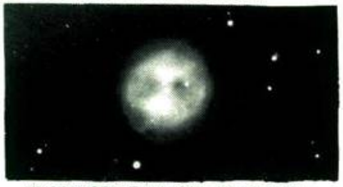

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Film Type, 35mm	**Exposures**	**Price**
2415, Ultra-fine B&W, red sens.	36	**$10.95**
SRV3200, fastest of all, color neg	24	**$13.95**
Konica SR3200, unhypered	24	**$8.50**
Konica SR400, fine grain color neg	12	**$10.95**
3M 1000, fastest slide film	12	**$12.95**
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Computer-Controlled Digital Setting Circles, only $498

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LUMICON SKY VECTOR™ computer, showing digital readout of coordinates, and easy-to-use controls. Shaft encoders are included (not shown). The coordinates are for Minkowski 1-79, a 13th mag. planetary nebula.

The LUMICON SKY VECTOR™ is a computer-controlled digital setting circle system. It represents a break-through in both computer performance and low price. To find an object just move the telescope until the coordinates of the SKY VECTOR™ match those of the object desired.

Each LUMICON SKY VECTOR™ includes one computer with digital readout, two precision digital shaft encoders, connecting cables, & mounting hardware (for most popular telescopes). **Specify telescope.**

Incredibly Smart!
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Incredibly Easy!

- Digital right ascension readout to 1 minute of R.A.
- Digital decl. readout to 10 arc-min
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- Motor drive ***not required!***
- Polar alignment ***not required!***
- Just sight two stars!

The computer's sophisticated program (over 3000 lines of code) determines **everything** from an initial sighting of just two stars!

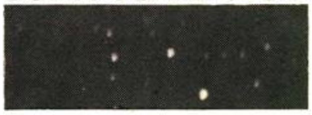
- **No need** to enter latitude, longitude, sidereal time, date, etc.
- Works **equally well** for alt-azimuth telescopes like Coulter Odyssey and equatorial mounts like C-8, Meade 2080. The computer automatically knows the difference.
- Uses Epoch 2000.0, 1975.0 or 1950.0 coordinates.
- Light weight, only 2 oz. permits mounting near the eyepiece, if desired. Only 2.6"x2.6"x1".
- 9V Battery lasts many nights.

LUMICON SKY VECTOR™ for Meade 2080,2120,C-8,C-11, *(Specify)*	**$498**
For Celestron-14 .. **$525.** For any alt-azimuth (Dobsonian) telescope	**$498**
For Coulter Odyssey 8", 10", 13", 17½" *(Specify telescope)*	**$498**
SKY VECTOR KIT. You must supply adapting hardware. For skilled ATM's only	**$449**

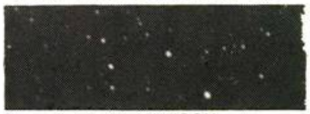
Reference catalogues listing coordinates of 1000's of objects

Burnham's *Celestial Handbook,* Vol. I, II, III (Epoch 1950.0)	**$36.85**
The *Revised New General Catalogue* (all NGC and IC, Epoch 1975.0)	**$35.00**
Sky Catalogue 2000.0, Vol. II, doubles, variables, deep-sky objects	**$29.95**

COMA CORRECTOR



Coma 1 inch off-axis 17½" f/4.5



Same field with LUMICON coma corrector; smaller, more numerous stars.

This computer-designed LUMICON 2" lens reduces coma and flattens the field for both viewing and photography. It threads into LUMICON 2" EASY-GUIDERS for effortless installation. This lens is optimized for f/4.5 and reduces aberrations for f/3.5 to f/5 Newtonians. Off-axis images are much smaller, making off-axis guiding far easier and yielding round pinpoint star images in photos. Since star images are sharp over a full 2¼" circle, you can use medium format cameras in addition to 35mm cameras. This zero power lens does not change image scale nor shift focus, and all lens surfaces are multi-coated for highest efficiency. Although designed for photography you may also use this lens to improve image quality in wide-field viewing with low power eyepieces.

LUMICON Coma Corrector/Field Flattener Lens	**$285.00**
LUMICON 2" EASY-GUIDER	**$169.50**
2" EASY-GUIDER (Mamiya 645)	**$199.50**
Adapter for Hasselblad	**$185.00**
Adapter for Bronica SQ-A	**$175.00**
2" Extension for viewing	**$26.00**

1.5x, 1.8x MULTIPLIER LENS

1.8x Multiplier Lens

The computer-designed LUMICON 2" Multiplier/Field Flattener multiplies the image scale in photography by 1.8x (f/4.5 becomes f/8). Use it with any LUMICON 2" EASY-GUIDER. It multiplies by 1.5x without the included extension tube. This lens is optimized for f/4.5, but will work well with any optical system. It may also be used visually as a highly corrected 2" Barlow lens.

LUMICON 1.5x/1.8x multiplier lens	**$195.00**

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FROM $49.50

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Select your desired base-plate shape! Flat, 7" OD, 9½" OD, 12½" OD, 16" OD, 21" OD, SUPER-FINDER base plate.

LUMICON 1¼" Helical Focuser	**$49.50**
LUMICON 2" Helical Focuser	**$59.50**
LUMICON Non-rotating Helical Focuser	**$79.50**
2" rack & pinion low profile focuser	**$139.00**
3 handles (see photo) for non-rotat. focuser	**$12.95**
2"/1¼" **adapter** w/48mm filter threads	**$20.00**
2" LUMICON EASY-GUIDER	**$169.50**

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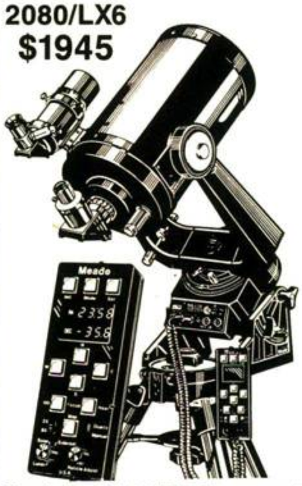
2120/LX6 10" f/6 . **$2495**

Digital readout system for 2080/2120/LX6	**add $475**
8200 object memory CAT computer	**add $1195**

NEW 2080/LX6 $1945



Meade Model 2080/LX6: The most advanced Schmidt-Cassegrain telescope available today. The hand-held electronic command center controls all telescope functions, and has digital coordinate readout available as an option. The f/6.3 optics yield 2½x shorter exposures in astrophotography.

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MTS-SC8, 8" f/10 w/drive, MCOG	**$998**
MTS-SC8 w/LX3 drive, MCOG	**$1198**
2080/LX3, 8" f/10 w/MCOG	**$1389**
2080/LX5, 8" f/10 w/MCOG	**$1589**
2120/LX5, 10" f/10 w/MCOG	**$1995**
2120/LX3, 10" f/10 w/MCOG	**$1799**
2045/LX3 4" f/10 w/LX3 drive	**$795**
#39 declination motor for LX5	**$109**
#38 (LX3) or #38A (2045) dec. mtr.	**$99**
Dew shield - essential! 8" **$65;** 10"	**$98**
LUMICON EASY-GUIDER for 2080	**$225**
EASY-GUIDER (f/4-f/10) for 2120	**$395**
CAT command control, 8200 objects	**$1195**

MEADE SCHMIDT-NEWTONIAN TELESCOPES

MTS-SN6, 6" f/5, #788 drive	**$649**
MTS-SN6 w/drive, MCOG	**$698**
MTS-SN8, 8" f/4 w/drive, MCOG	**$795**
MTS-SN8, 8" f/4 w/LX3 drive, MCOG	**$1048**
#36 LX3 hand cntrl. & #38 dec. motor	**$189**

MEADE NEWTONIAN TELESCOPES

Model 826C 8" f/6 w/motor, 2" focuser	**$975**
Model DS-10A, 10" f/4.5 w/mtr., 2" focus.	**$975**
Model DS-16A, 16" f/4.5 w/motor, 2" focuser	**$1975**
Model DS-16A w/Sealmaster ball bearings for photography	**$2195**
8X50mm finderscope w/brackets for DS-10,-16	**$109**

48mm COLORED GLASS FILTERS

These 48mm Filters thread into LUMICON EASY-GUIDERS and most 2" eyepieces. Use adapter for 1¼" eyepieces. AR Coated.

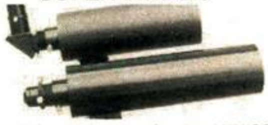
Filter:	**Bandpass**	**Trans**	**Price**
Ultraviolet	320-420nm	85%	$35
Minus Violet	420nm-IR	96%	$29
Blue Tricolor	340-470nm	80%	$35
Hi Perf. Blue	300-540nm	95%	$35
Yellow	480nm-IR	98%	$18
Green	490-590nm	60%	$18
Orange	560nm-IR	98%	$18
Red	600nm-IR	98%	$18
H-Alpha Pass	640nm-IR	95%	$35
Cyan	340-580nm	95%	$59
Adapter for 1¼" eyepieces			$20
Set of all 10 48mm filters ($340 list)			$298

EYEPIECE PROJECTION

These adapters allow high magnification photography of the Moon and Planets using eyepiece projection. They may be used without any eyepiece for prime-focus photography. All adapters use standard camera T-rings.

Tele-Extender for Meade or Celestron SCT.	**$32**
1¼" Basic Camera adapter, 2 part system	**$32**
0.96" Basic Camera adapter, 2 part system	**$32**
1¼" prime Focus adapter, fits 1¼" focuser	**$22**
0.96" prime Focus adapter, fits 0.96" focuser	**$22**
Camera T-ring, specify 35mm camera type	**$12**

LUMICON 50mm, 80mm SUPER-FINDER™



Visual Astronomers prefer the LUMICON 80mm SUPER-FINDER™, since hundreds of deep-sky objects, including most Messier objects, are visible directly. SUPER-FINDERS also make nice small portable telescopes. 80mm aperture, F=300mm coated achromat. The deluxe SUPER-FINDER uses an 80mm, F=500mm air spaced achromat.

1¼" 50mm Finderscope **$59.50**, right-angle	**$89.50**
1¼" straight-thru 80mm SUPER-FINDER	**$169**
1¼" right-angle version, w/star diagonal	**$195**
2" right-angle version, non-rotating focuser	**$199**
1¼" Deluxe right-angle Super-Finder*	**$279**
2" Deluxe right-angle Super-Finder*	**$309**
25mm Cross-hair 1¼" eyepiece (12X)	**$29**
*1¼" Star Diag. **$32**, 2" Star Diag., silver,	**$145**
1¼" Amici Prism diag. for correct left-right views	**$69.50**

2" ADAPTERS MEADE, CELESTRON TELESCOPES

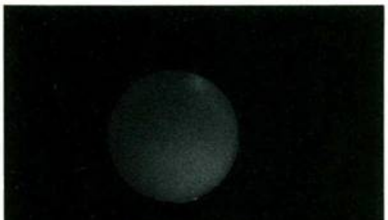
These adapters convert refractors and Schmidt-Cassegrain telescopes for 2" operation. They allow use of 2" accessories, such as the LUMICON 2" EASY-GUIDER for photography. They also allow use of 2" eyepieces and/or 2" star diagonal for viewing.

2" adapter for C-8, Meade 2080, etc.	**$26.00**
2" adapter for Criterion 4000, 8000	**$26.00**
2" adapter for C-80, C-90, C-100	**$39.50**
2" adapter for C-70, C-80F, C-90F, C-100F	**$39.50**
2" Accessory adapter for Comet Catcher*, C-6*, Meade 310, 320 refractor	**$30.00**
2" adapter for Takahashi E-130, 160	**$59.50**

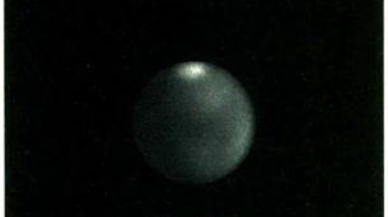
Memories of MARS

Observers had clear views of Mars during the 1988 opposition until November when global dust storms obscured much of the Red Planet.

by David J. Eicher and Daniel M. Troiani


July 23, 1988

July 31


August 7

August 21

August 26

What a wonderful year it was for Mars. Of the forty-two Martian oppositions this century, 1988's was one of the most favorable. And it was certainly the best within memory: by a powerful combination of circumstance and good fortune, amateur astronomers around the world experienced the finest views of Mars they had ever seen.

Participation by amateurs in organized observing programs was correspondingly high. According to Donald C. Parker, Jeff D. Beish, and Carlos E. Hernandez, Mars Recorders of the Association of Lunar and Planetary Observers, amateurs contributed over four thousand observations of the Red Planet through the International Mars Patrol, a network of observers formed by the late planetary scientist Charles E. Capen. These and other reports sent to Marswatch '88, an archiving project run by the Planetary Society, will be analyzed thoroughly now that the opposition is over.

An opposition of Mars happens about every two years when orbital geometry places Mars opposite the Sun in the sky. The planet rises as the Sun sets, which means it is perfectly placed for nightlong observing. Favorable oppositions occur only every fifteen to seventeen years, and last year's was favorable. The fact that Mars was located near the celestial equator in Pisces meant the planet could be viewed from both hemispheres — and it was placed unusually high in the sky for Northern Hemisphere viewers.

The 1988 opposition was also perihelic, occurring when Mars was near its closest point to the Sun. (Unlike Earth's orbit, Mars' orbit is noncircular, so the planet's distance from the Sun varies considerably.) The circumstances could not have been better. At closest approach Mars lay only 35 million miles from Earth, and the Red Planet's disk swelled to over 23″ across. At this large image scale observers with small telescopes could see a surprising amount of detail on the planet.

Good fortune also played a part in the 1988 opposition. Normally when Mars approaches the Sun, rising temperatures on the planet's surface help stir up large dust storms that can obscure Martian surface details for weeks. Global dust storms hindered observations of surface features during the Martian oppositions of 1956, 1973, and 1977. Much of the planet became obscured by dust during the last perihelic opposition in 1971. However, in 1988 no major dust storm occurred until late November, two months after opposition and after the planet had shrunk to 14″.

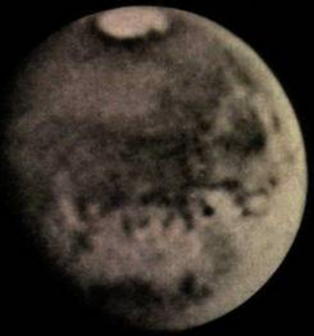
The 1988 opposition gave viewers an unrivaled opportunity to see four categories of Martian phenomena. Most apparent were the large albedo features, light and dark areas on the planet's surface. No one failed to notice the planet's South Polar Cap, which sublimated away over the summer. Careful-eyed telescopists could spot Martian atmospheric phenomena: small clouds, fogs, and hazes along the planet's limb were occasionally visible. Although a large dust storm failed to materialize until November, when it did arrive, a small refractor showed the storm's presence as a brightening in the planet's southern hemisphere.

Martian Surface Features

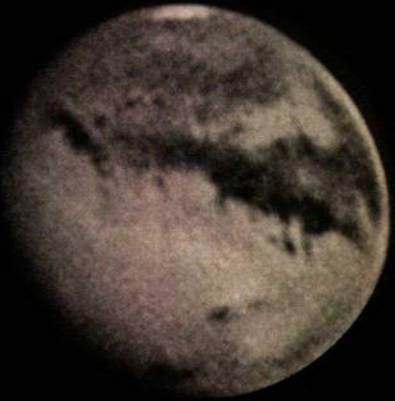
Probably the most recognizable feature on the surface of Mars is Syrtis Major, a large, dark, wedge-shaped feature (Martian longitude 290°, latitude +10°). Syrtis Major and other dark areas are not physical features on the Martian surface but simply areas of low reflectivity. Planetary scientists believe such albedo features are caused by varying amounts of debris scattered on the Martian surface. Generally, dark areas are relatively free of

Martian Surface Features

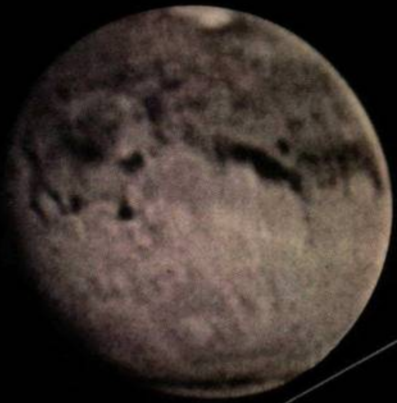
The unusually clear opposition of 1988 gave observers a superb view of surface markings on the Martian disk. Dark, roundish Solis Lacus; wedged-shaped Syrtis Major; and the bright Hellas basin were prominent throughout the opposition.



August 18



September 9



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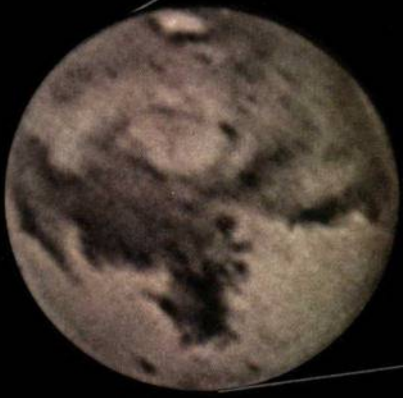
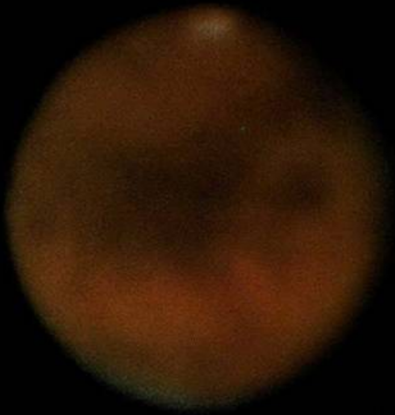
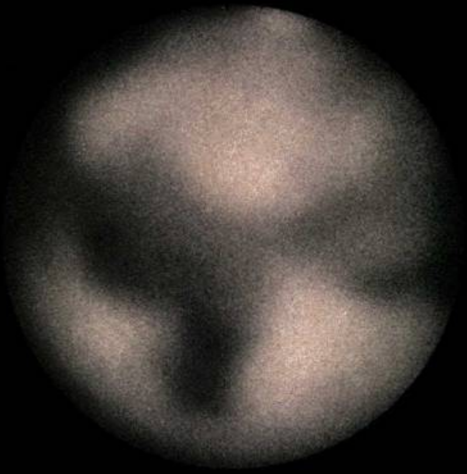


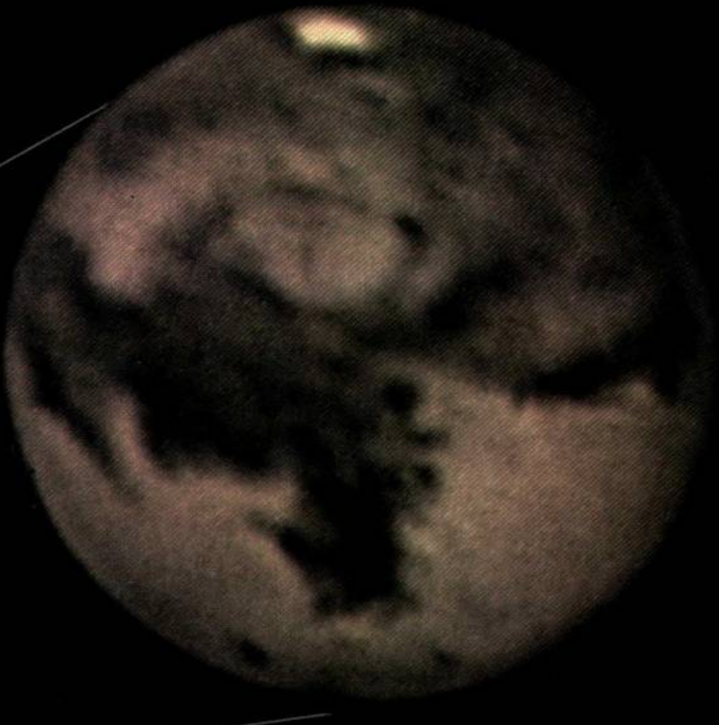
October 3



THE "EYE OF MARS," Solis Lacus is visible as a dark patch above and right of center in this image made on October 21, 1988. Photo by Donald C. Parker.



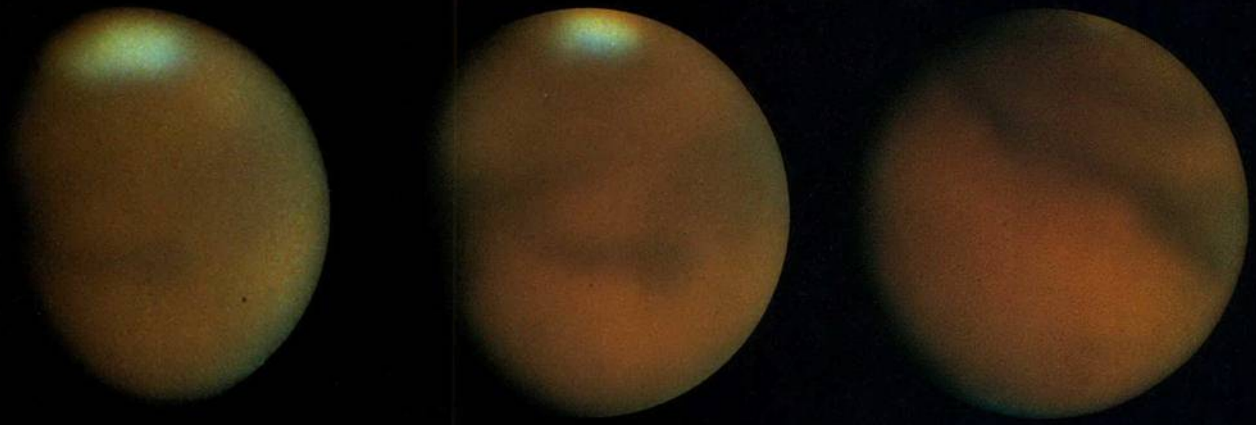
HELLAS SHINES BRIGHTLY as dust in the great basin reflects sunlight. Hellas is the bright spot above center on the Martian disk. Photo by Jean Dragesco.



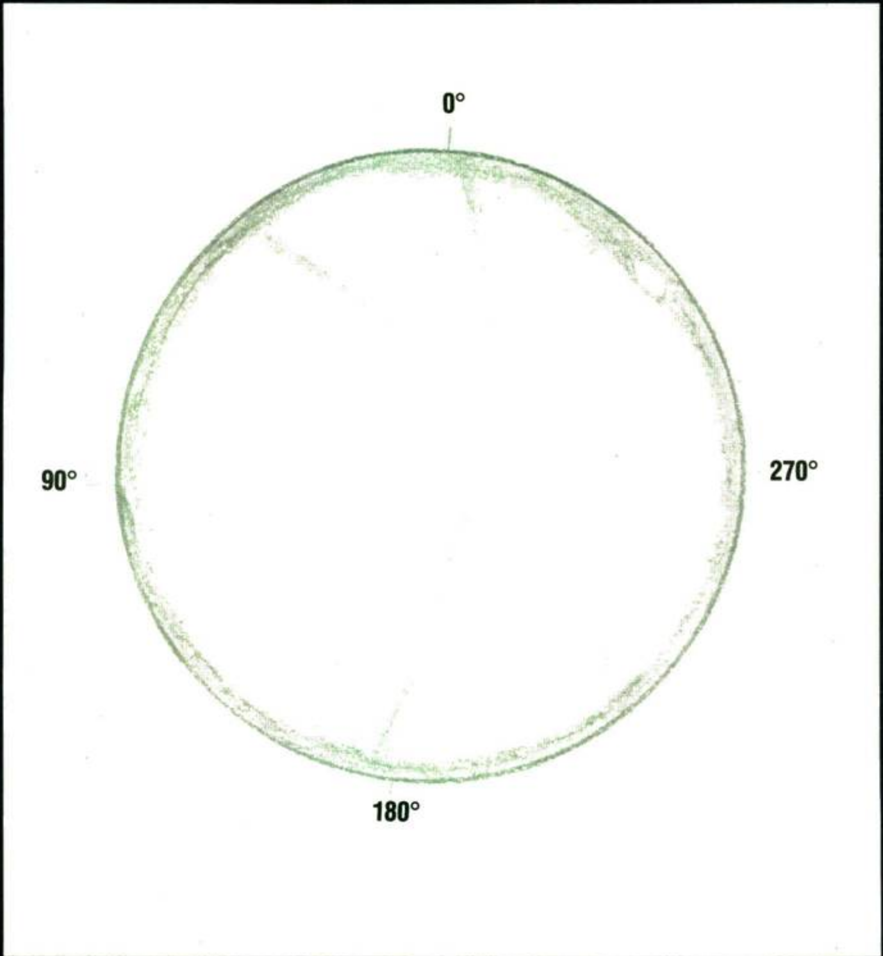
LANDMARKS ON MARS are visible in the sequence at left made in red light with the University of Arizona's 61-inch Catalina telescope and a CCD camera. Together the four images show most of the surface of Mars. Each image is reproduced at the same angular scale. The enlargement above shows Syrtis Major. University of Arizona Lunar and Planetary Laboratory photos by Stephen M. Larson and Gary Rosenbaum.

The South Polar Cap Melts Away

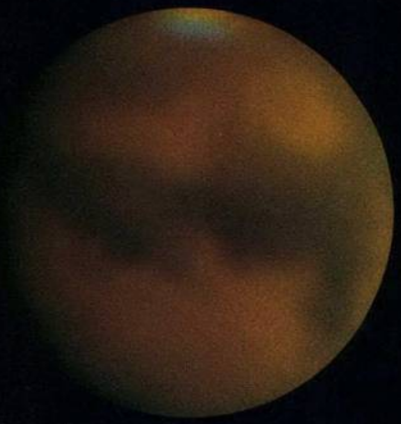
Last summer the South Polar Cap on Mars shrank as Martian summer came to the planet's southern hemisphere. By late August sharp-eyed Mars watchers picked out the "Mountains of Mitchell," a small ice-covered ridge that looks like a detached piece of polar cap.



A POLAR CAP THAWS over fifty-one days last summer. On July 14, 1988 (left), the Red Planet's South Polar Cap is prominent. On August 17 (center) the cap is smaller despite the planet's overall greater size. By September 3 (right) the cap is virtually gone. Photos by Donald C. Parker.



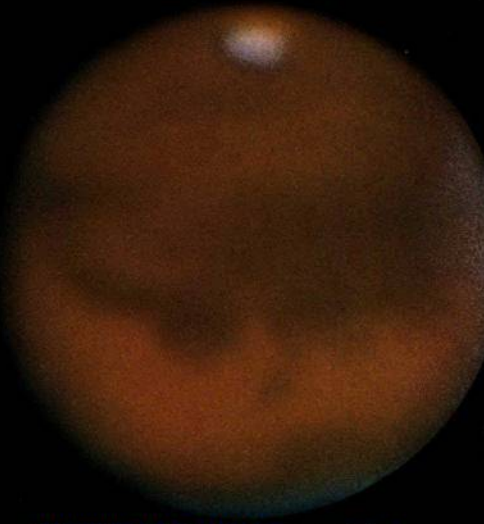
RIFTS SPLIT THE POLAR CAP as seen from above the Martian south pole. Dan Troiani sketched polar cap rifts between June and September 1988 and produced a composite view showing their appearances from above the pole.



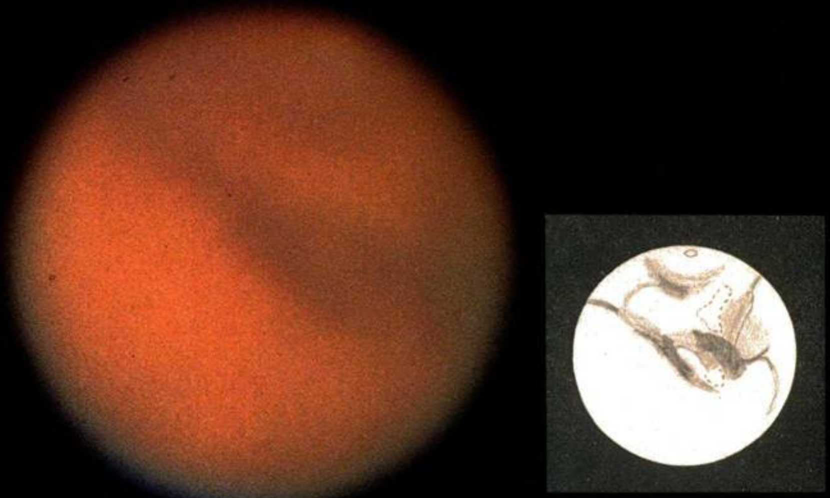
THE MOUNTAINS OF MITCHELL are visible as a small swirl of light curving away from the South Polar Cap. Named after its discoverer, the feature is an elevated ridge that retains frost after valleys below are ice-free. Photo by Donald C. Parker.

An Active Martian Atmosphere

Observers with sharp eyes and colored filters were able to spot atmospheric phenomena on Mars. For example, orographic clouds formed during Martian mornings over the equatorial volcanoes. Limb hazes and patches of fog were occasionally observable with blue and violet filters, and the North Polar Hood was frequently visible.



MORNING HAZE LINGERS over Solis Lacus on September 21, 1988. The haze is visible as a bluish brightening on the planet's limb. Also visible is the North Polar Hood. Photo by Donald C. Parker.



MARTIAN HAZE pervades small areas as indicated by dotted circles in the sketch at right, made on October 6, 1988. A photograph taken at the same time (above) shows the same areas as bright relative to the surrounding areas. Sketch and photo by Lee Keith.

dust and light areas contain lots of it. Dark features oriented east-west south of the Martian equator include Mare Tyrrhenum, Hesperia, Mare Cimmerium, and Sabaeus Sinus.

Another prominent dark feature is Solis Lacus (80°, −25°), a large, round spot called the "Eye of Mars." Solis Lacus is always eye-catching because it is one of the darkest features on the planet and surrounded by a ring of light-colored Martian landscape. During last year's opposition Solis Lacus appeared especially dark, which made it one of the most recognizable features in small telescopes. Throughout September observers spotted fine detail surrounding Solis Lacus that included dark spots and lines — areas blown free of dust.

An albedo feature that represents a real physical feature on the Red Planet is the large, circular, light-colored spot called Hellas (285°, −40°). Lying due south of Syrtis Major, Hellas is a shallow basin that acts as a giant dust repository and frequently is the starting point for Martian dust storms. Probably because of dust stirred up above its floor, Hellas appeared unusually bright during the 1988 opposition.

Throughout the spring and summer eagle-eyed observers spotted a number of new albedo features and other markings that appeared subtly different from previous observations. On April 26 the linear features Hydraotes, Lysis, and Nilokeras II, which are dark features linking Oleaster Lacus and Lunae Lacus, began to darken substantially. In June observers rediscovered four dark features — Acampsis, Eosphrous, Gallinaria Silva, and Noctis Lacus — that hadn't been seen since the nineteenth century. One month later amateurs using small telescopes spotted a new dark, canal-like feature connecting the features recovered in June.

The Polar Cap Melts Away

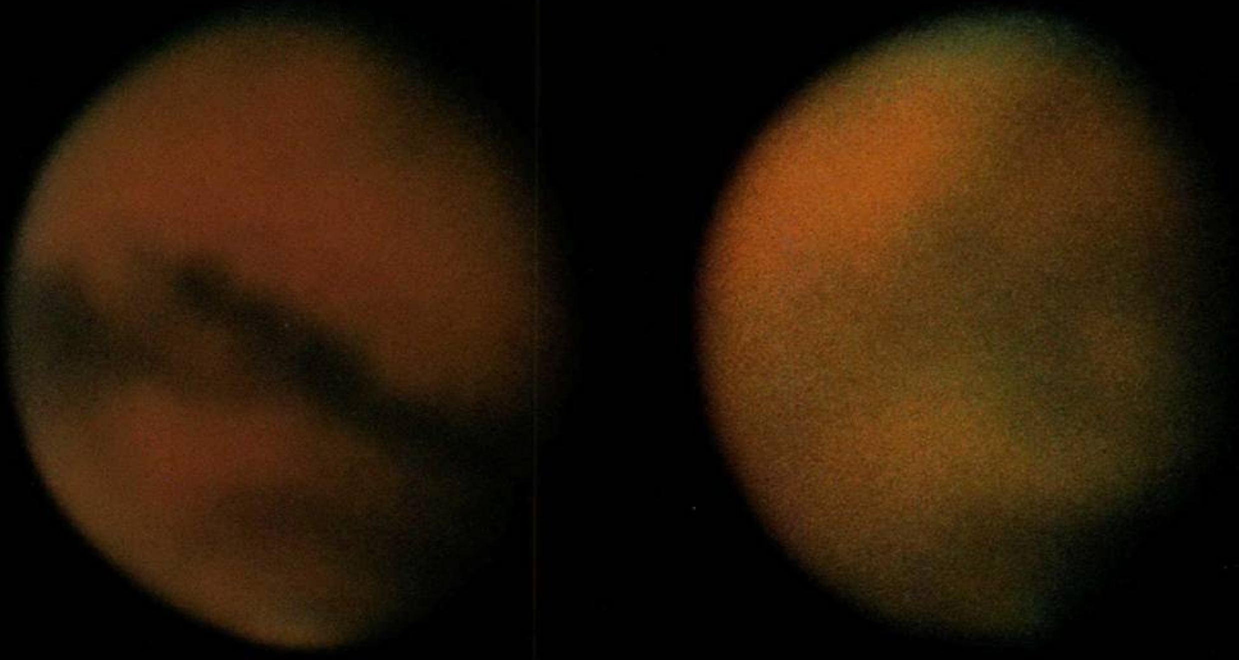
The most visible change on Mars during the 1988 opposition was the shrinking South Polar Cap. Last spring the cap was plainly visible in 2-inch telescopes as a stark white oval ringing the planet's south pole. But as springtime in the southern hemisphere of Mars warmed the planet, the South Polar Cap began to melt. By June 1988, when the planet's disk exceeded 10″, the polar cap had clearly diminished in size and brightness. Throughout July and August the cap shrank dramatically, and during the weeks after opposition it had virtually disappeared. By early 1989 only a tiny remnant could be seen.

Observers with large telescopes reported seeing details associated with the polar cap. Occasionally viewers reported small, bright spots inside the polar cap. Between June and September several dozen observers sketched small, linear rifts that gave the cap a fractured look. One of the largest rifts broadened and became a prominent dark feature called the Rima Australis. At one time, three rifts were visible simultaneously. Mars observers hope to learn something about how the polar cap melts by analyzing the formation of these rifts.

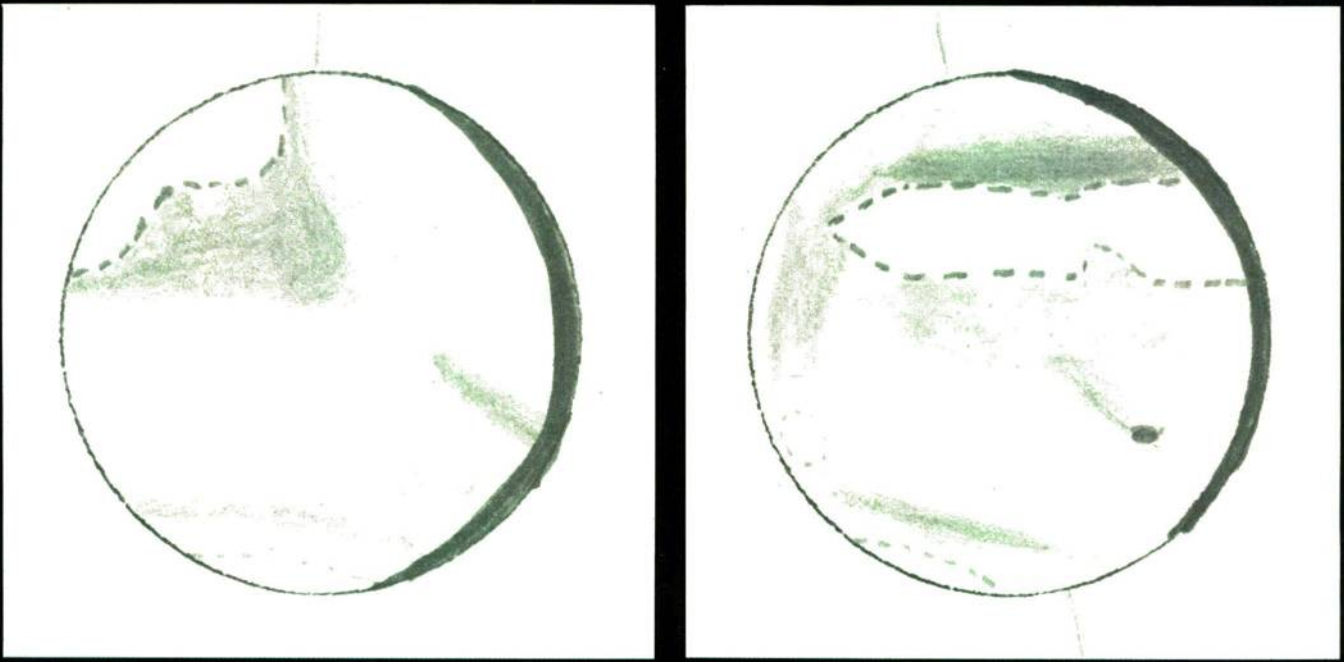
The most celebrated polar cap feature is Novissima Thyle (320°, −80°), an elevated ridge that retains ice for some time after the surrounding plains are frost-free. The result is that Novissima Thyle, nicknamed the "Mountains of Mitchell" after its discoverer, looks like a small, detached piece of the polar cap. Last year the Mountains of Mitchell were first spotted in late August and remained visible in small telescopes for several weeks. According to Parker, the Mountains of Mitch-

The Great November Dust Storm

A dust storm in Mars' southern hemisphere obscured much of that hemisphere last November. Fortunately last year's big storm came late, after observers had already experienced months of clear Mars watching.



DUST ROSE ON MARS last November as the Red Planet receded from opposition. Before November 25, dark markings were plainly visible in the planet's southern hemisphere (left). By November 28, however, nearly half the planet was enshrouded in dust. After several weeks of obscuration the storm subsided. Photos by Donald C. Parker.



LIKE A GLOWING VEIL, a blanket of dust reaches across the planet's southern hemisphere. Dan Troiani's sketches show that on November 24 (left) the storm was growing; five days later it enveloped a 3,300-by-900-mile swath of Martian surface.

ell were last photographed by the Japanese observer Isao Miyazaki on September 11.

Clouds, Fogs, and Hazes

Backyard astronomers armed with moderate or large telescopes and a set of colored filters watched for Martian atmospheric phenomena — clouds, fogs, and hazes. For example, orographic clouds, small white circular features visible near the Martian equator, form around local noon when moist air rises over volcanoes near the Martian equator. They were occasionally visible to sharp-eyed observers with blue or violet filters and became increasingly visible by early November. Afternoon clouds over the volcano Arsia Mons (100°, +10°) were especially prominent. Between mid-October and early December Libya (270°, 0°), a plain east of Syrtis Major, displayed considerable cloud activity. That features so small and distant can be observed with small telescopes is amazing.

Also occasionally visible were limb hazes, layers of morning fog appearing as a slight brightening along the planet's limb. The haze layers are thought to be composed of carbon dioxide crystals suspended in the planet's atmosphere. Small telescope observers also glimpsed the North Polar Hood, a blanket of ice and frozen carbon dioxide opposite the South Polar Cap. The polar hood appeared especially prominent during September.

Filters play a key role in identifying the violet clearing, a phenomenon visible only when the planet is observed through a violet filter. Normally features on Mars appear vague when viewed in violet light, probably because of dust scattered in the atmosphere. When the planet's features are easily visible in violet light — as they were in June and during parts of September and October — the Martian atmosphere is exceptionally free of dust.

The Big Dust Storm

Mars isn't always free of dust, however. Global dust storms worried Mars observers in 1988 because the storms have spoiled past oppositions. In 1988 a large dust storm did occur, but only in late November, several weeks after the prime observing period had ended. (By the time the storm began, the planet was receding from Earth and spanned only 14″.) In 1988 Mars observers got lucky — they were able to see the planet in all its glory.

When the storm did come, it hit suddenly. On November 23, Chicagoans Dan Troiani and Dan Joyce spotted a yellow cloud near Nectar (75°, −25°) in the region of Solis Lacus. The cloud was independently spotted by observer Bob Robinson. On November 25, Beish reported two dust clouds, one over Nectar and the other extending from southeastern Thaumasia (75°, −35°) westward across Bosporus into Argyre I (40°, −40°). Despite the Thanksgiving holiday, word spread throughout the United States and a number of observers began to follow the storm.

During the final days of November the dust storm lifted high into the atmosphere and covered much of the planet's southern hemisphere. Surface details were gone — all that could be seen was a light band. By December 1 the storm had spread eastward into Noachis (0°, −40°), covering 750 miles in 72 hours.

Japanese observers reported the storm's westward spread into Phaethontis (150°, −45°) and Daedalia (120°, −25°). Using these data, Beish and Parker calculated that at its height the storm blanketed an approximately 3,300-by-900-mile patch of the Martian surface.

As Mars shrank to 11″ in December, observers saw the dust storm subside. The planet was moving away from the Sun and was no longer warm enough to sustain a planetwide dust storm. The Great Dust Storm of 1988 blanketed the planet's southern hemisphere but fell short of becoming global.

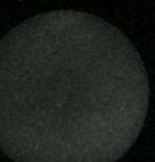
Gearing Up for 1990

The 1988 opposition ended just months ago, yet already observers are gearing up for the next Martian opposition, which occurs on November 27, 1990. On that date the Red Planet will again be well placed for Northern Hemisphere observers, achieving a culmination of 75° as viewed from the central United States. The planet will measure 18″ across, not as large as its diameter of 24″ in 1988, but much larger than normal.

In 1990 the north pole of Mars will be tipped toward the Sun. The North Cap is composed of water-ice almost exclusively, so that as it melts, large numbers of small white clouds composed of water vapor should be visible in the north polar region.

The 1988 opposition of Mars is now merely a memory. The opportunity for small telescope views of surface features, atmospheric phenomena, and dust storms on Mars is gone. Yet those memories of Mars will have faded only slightly before we all get another close look at the Red Planet nineteen months from now. □

Daniel M. Troiani lives in Schaumburg, Illinois, and is assistant Mars Recorder for the Association of Lunar and Planetary Observers.



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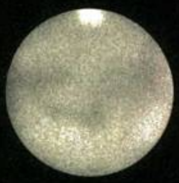

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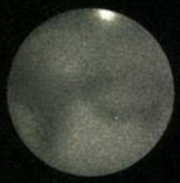

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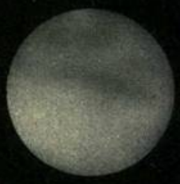

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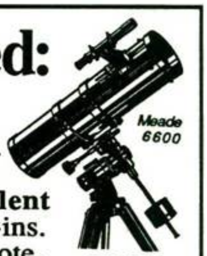

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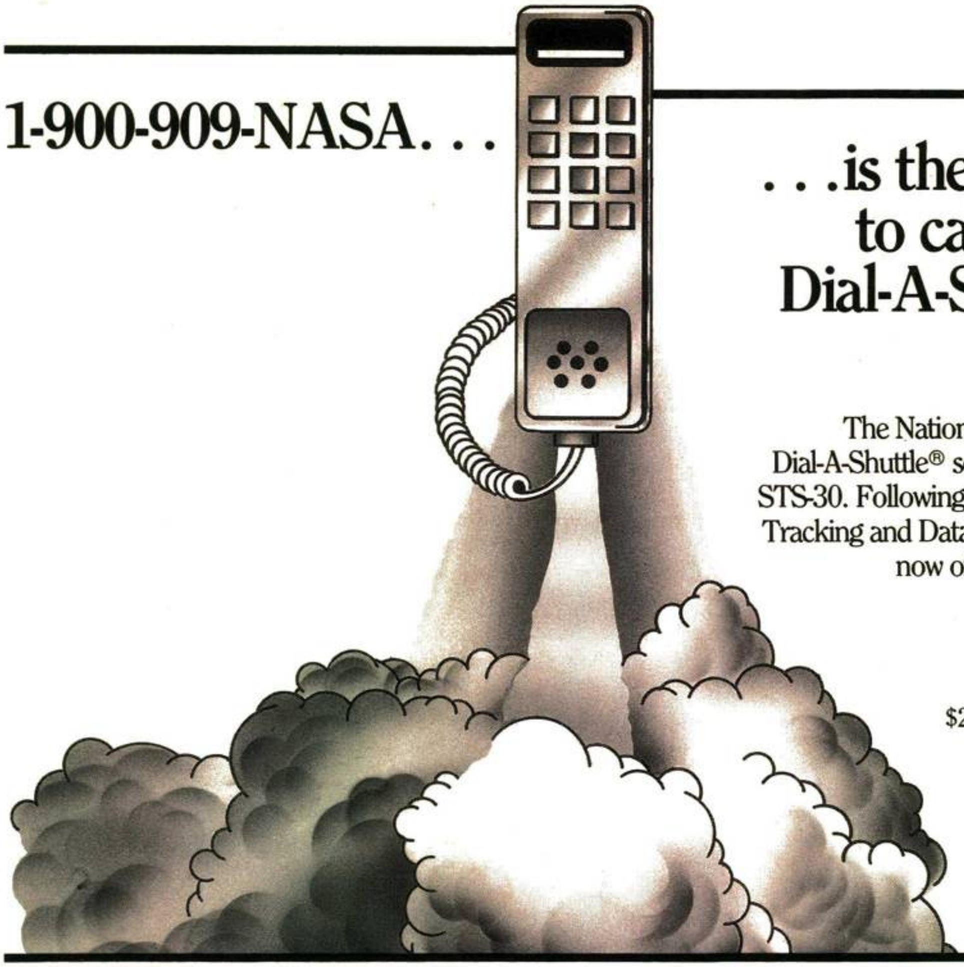

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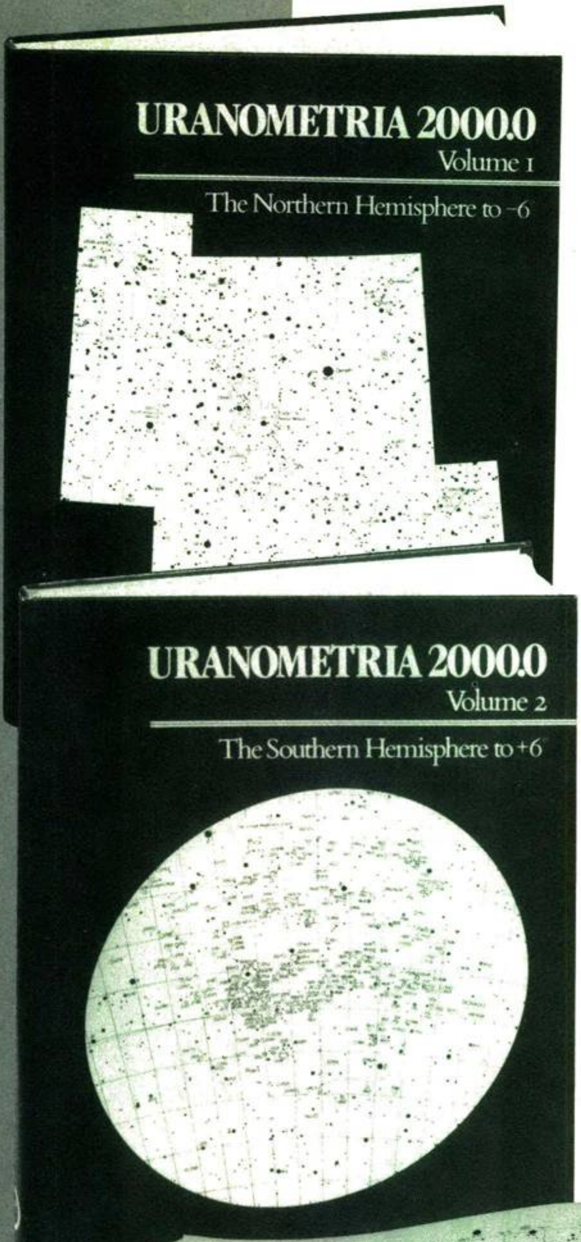

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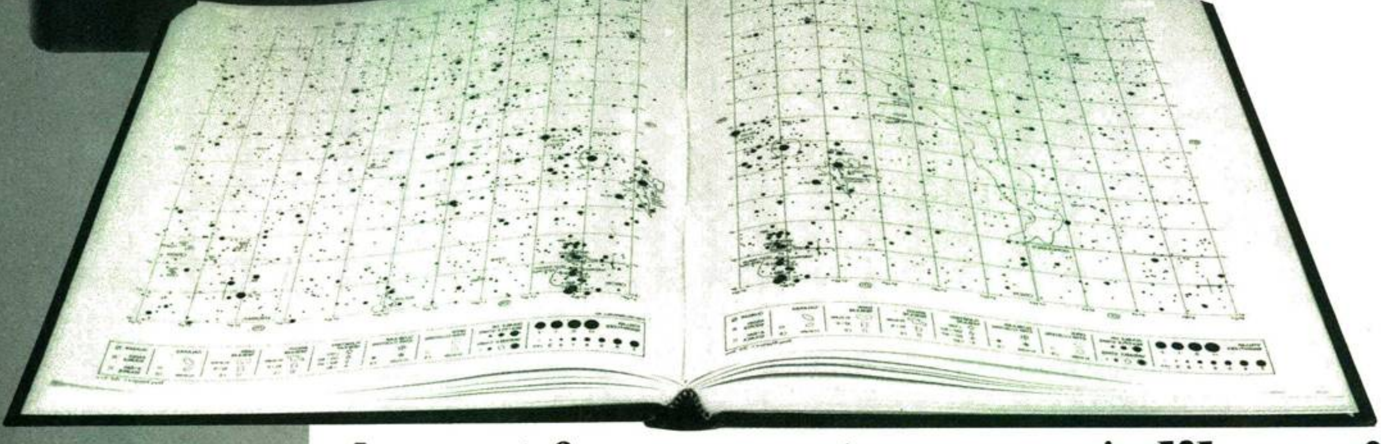

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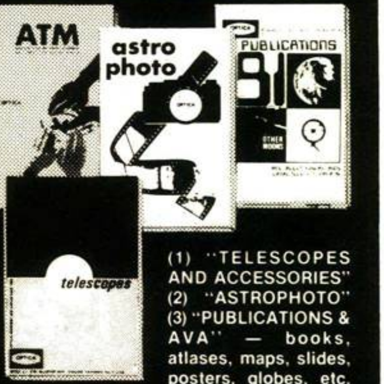

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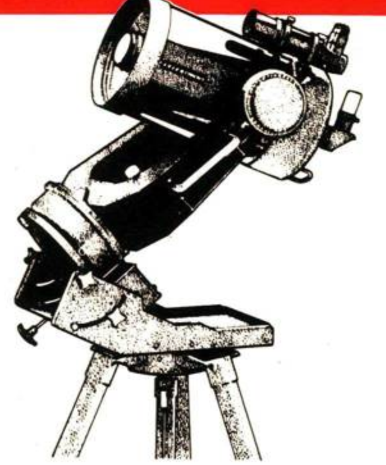

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GEMINIDS PROVIDE YEAR-END SKY SHOW

The Geminid meteor shower, which peaked on the night of December 12/13, 1988, replaced August's Perseid shower as the year's most active meteor display. Viewers under dark skies saw as many as fifty meteors per hour in the early morning of the 13th.

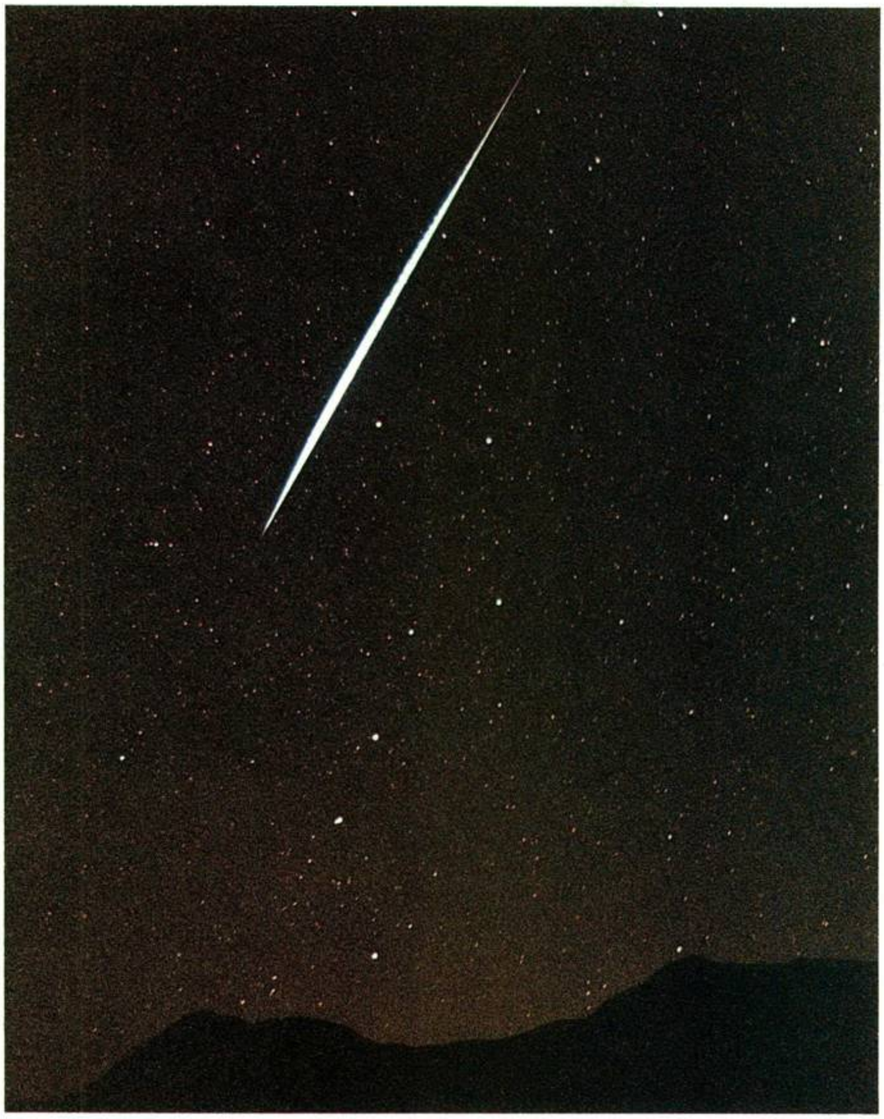
"This year again the Geminids proved they are better than the Perseids," said George W. Gliba of Greenbelt, Maryland. Each year Gliba observes major showers and compiles a statistical breakdown of the meteors he sees. "The Geminids showed rates about 25 percent higher than the Perseids under similar conditions," he concluded.

"The event started with a bang," Gliba continued. "While walking to my observing site at 10:33 p.m. EST, I saw a magnificent, −6-magnitude bolide that exploded near Sirius. Its trail began halfway between Procyon and Gamma Geminorum and had a deep yellow-orange color. Its terminal burst was an intense blue that reminded me of a welder's arc."

Gliba recorded Geminids over two one-hour blocks of time on the night of the 13th. Between 10:53 and 11:53 p.m. he observed forty-three Geminids and five sporadic, or random, meteors. The brightest was a −2-magnitude yellow fireball, and the others ranged from 1st to 4th magnitude. Most were blue-white, white, or yellow in color, and only the brightest four left trains. During the second hour, between 11:58 p.m. and 12:58 a.m. on the morning of the 14th, Gliba spotted thirty-one Geminids and six sporadics, including three −1-magnitude fireballs.

On the night of the 13th, David Stine of Tulsa, Oklahoma, made a similar log of meteors he observed. "After driving to a reasonably dark sky near Catoosa, Oklahoma, I began recording meteors at 10:18 p.m. CST and saw twenty meteors during the first hour," explained Stine. "During this period I saw several bright meteors including one −1.5-magnitude bluish white bolide that left behind a smoky green train."

Stine started a second hour of observing at 1:13 a.m. "During this session I recorded twenty meteors, including the unusual sight of two meteors apparently crossing each other seconds apart and forming an 'X'! At 2:15 I began getting sleepy and packed up my gear to return to Tulsa. As I pulled into my driveway at home, a flash lit the yard for an instant and I looked up to see a −2.5-magnitude fireball. I got to see one last meteor before going indoors and falling asleep."

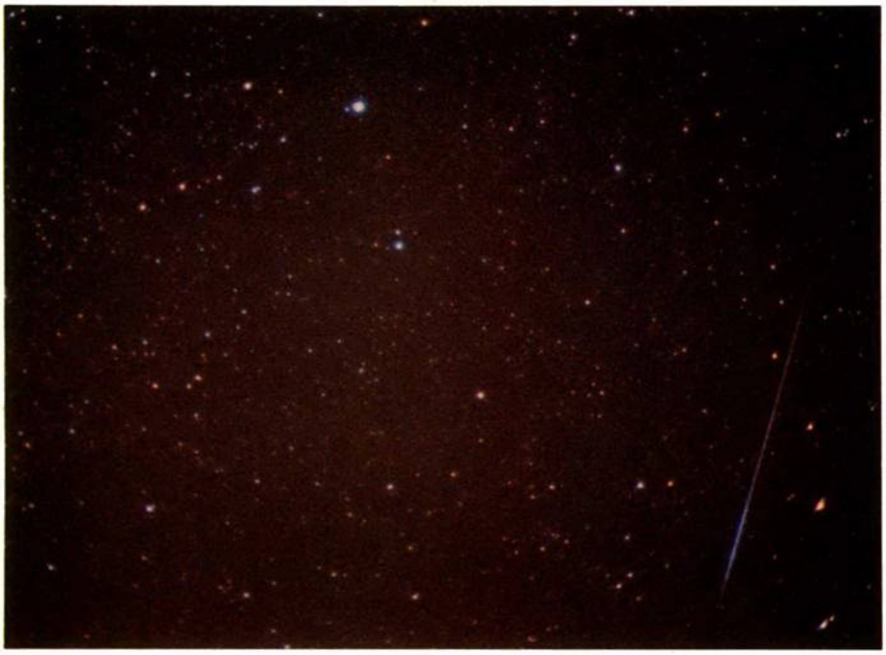


A BRILLIANT FIREBALL flashes past the Big Dipper during last December's Geminid meteor shower. Photo by Lance Oldham.

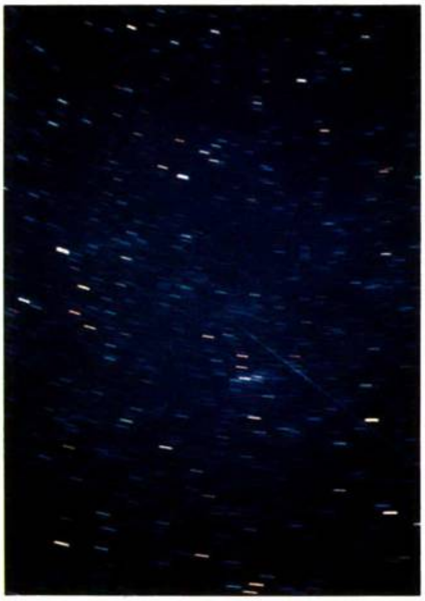
From Halifax, Nova Scotia, Michael Boschat planned to travel some thirty-five miles to a dark sky site for the Geminid shower until he came down with influenza. "The flu bug got me," said Boschat. "My observations were limited to looking out my front window, which was closed because of the −21° C temperature outside.

"Nonetheless," Boschat said, "I began observing the shower on the morning of the 13th and saw twenty-three meteors over three hours. Because of my observing site, the ones I saw were bright — the average magnitude was −1. One of the nicest I saw was a slow-moving, −2-magnitude fireball that spanned 20° between Orion and Eridanus. Surprisingly I saw three meteors in only ten minutes that seemed to radiate from a point in Taurus at approximately 5h30m, +20°." Did other readers see meteors originating from this area?

Tim Printy of the Central Florida Astronomical Society spent the wee hours of December 13 observing the Geminid shower from very dark skies near the St. John's River in central Florida. "For numbers of meteors visible, this was an incredible year for the Geminids," explained Printy. "David Gilley, Don



A −2-MAGNITUDE GEMINID races through Ursa Minor and disappears in the bowl of the Little Dipper. Photo by Tim Printy.



CROSSING PERSEUS, a Geminid leaves its mark on film as a bluish streak in this 5-minute exposure on Fujichrome 400 film. Photo by Tim Printy.

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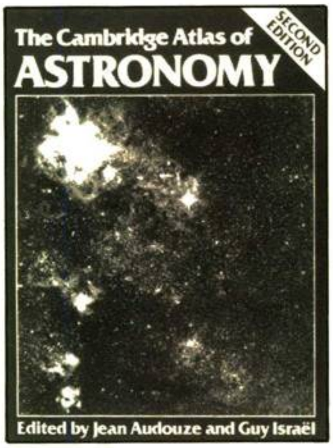

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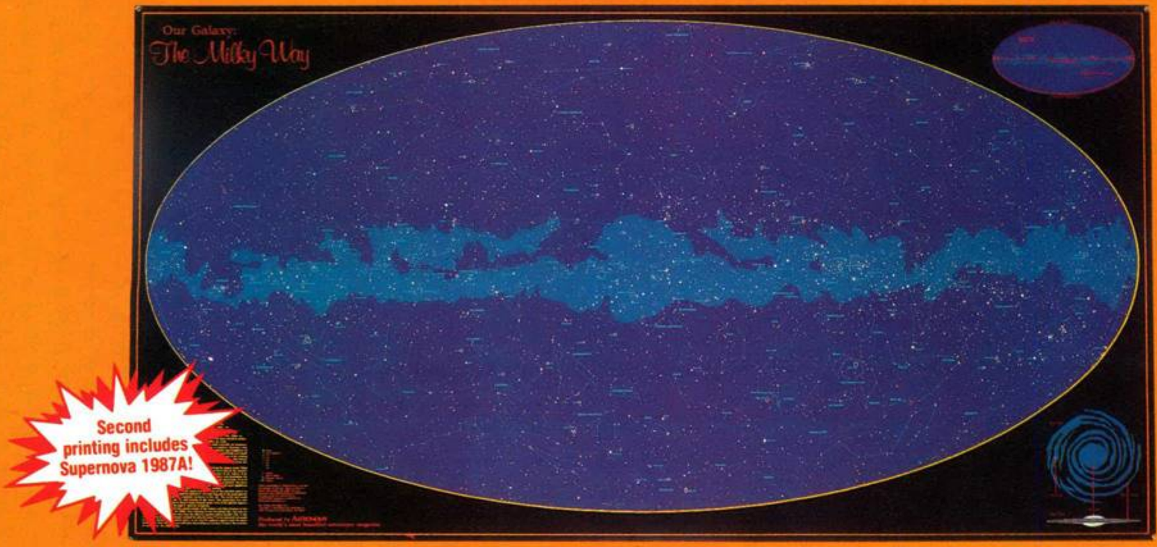

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STREAKING PAST M41, this Geminid typified the shower. It was a fast-moving, bluish white meteor that glowed at 2nd magnitude and left no train. Photo by Tim Printy.

Hall, Rick Smith, and I observed the shower and tallied some impressive results. Before midnight, rates hovered between twenty and forty meteors per hour, most glowing at magnitude 2 or 3. The typical Geminid was white in color and did not leave a train.

"However, after midnight, activity sharply rose," said Printy. "Between 2:18 and 3:18 a.m. the shower rate skyrocketed. We counted eight-eight meteors during that period, the most Geminids we have ever seen in such a short span. Most of these were fast, which made them relatively difficult to photograph. In the end we estimated that about 10 percent left trains, as opposed to 40 or 50 percent for the Perseids. The brightest Geminid we saw shone at magnitude −5.

"After viewing ten Geminid showers," Printy reported, "I'd have to say 1988's was the best. This year's event was the first some of our club's members had ever seen, and I think they were impressed. Although the Geminid shower occurs when temperatures are cold in many areas, it has a powerful effect on getting people interested in watching meteors." — *David J. Eicher* ☐

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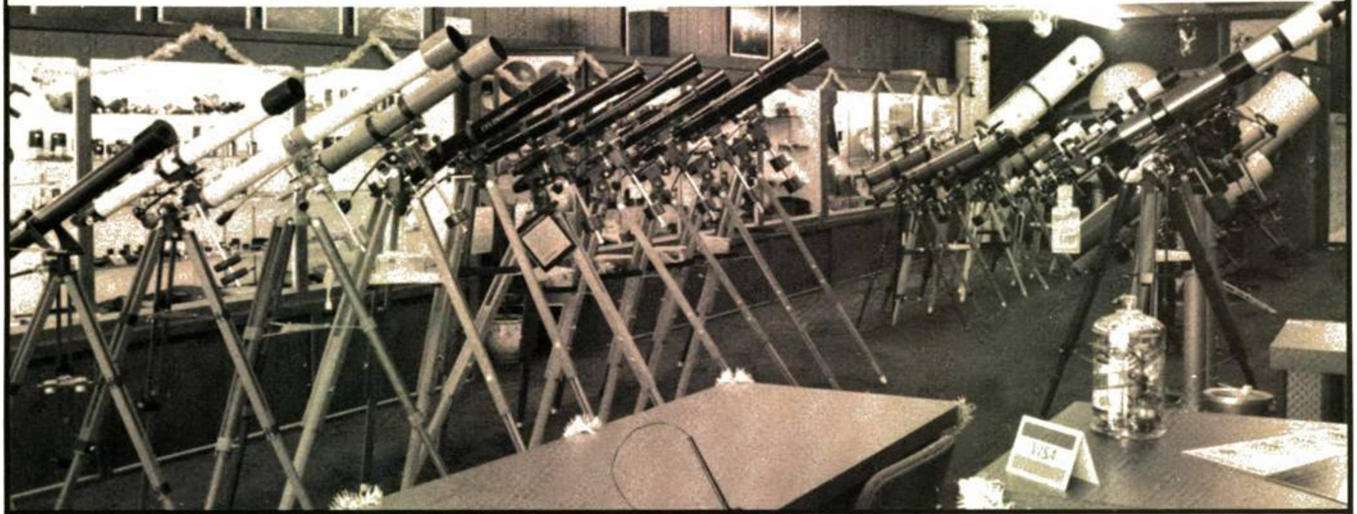

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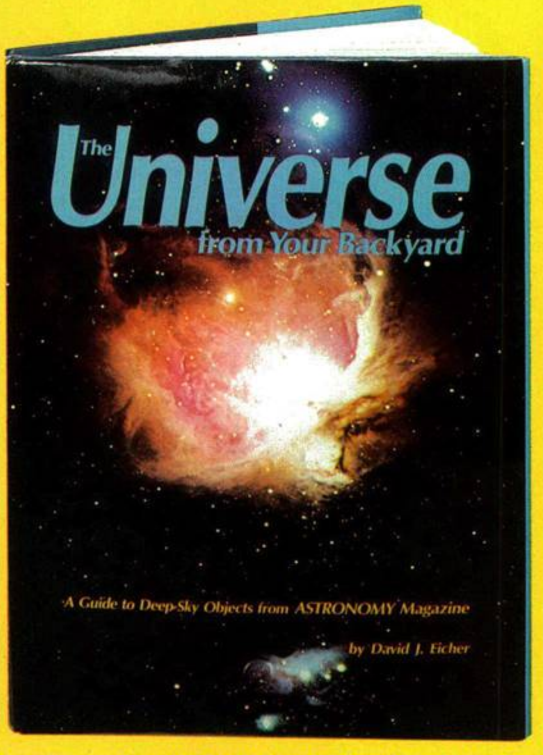
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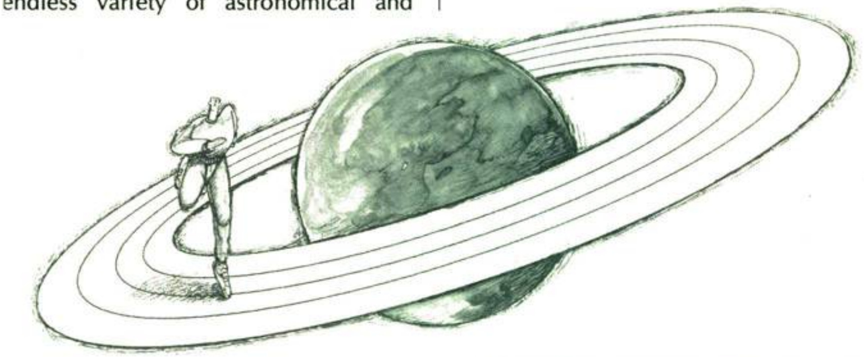
Early in the morning, three times a week, I run three to six miles on a quarter-mile track at a nearby junior high school that sits in the foothills of the Catalina Mountains north of Tucson. Only faraway outdoor lights and the nighttime sky glow shed light on the ground, but that is sufficient for safe running and great for astronomy. Since I began running before dawn, I have found that there is an endless variety of astronomical and meteorological phenomena to see in the predawn sky.



The views in all directions are superb. The sky darkness is surprisingly good even though the track is close to Tucson. On clear mornings before twilight begins, I can see stars as faint as magnitude 5.5, in addition to the Milky Way and the zodiacal light.

While exercising outdoors, I have found it isn't hard to work out the phases of the Moon and to understand the difference between waxing and waning. You can soon tell by a glance approximately how old the Moon is and when it should rise or set.

I constantly hone my knowledge of the constellations by identifying all those visible on a given morning and looking up any unfamiliar groupings when I get home. This has been particularly helpful in learning such constellations as Corvus, Crater, Lepus, Puppis, Draco, and Hydra.

Observing the positions of the planets is a never-ending source of delight. It is surprising how much they change from day to day, especially Mercury, Venus, and Mars.

I watch for meteors and perhaps four times a year see a spectacular fireball. One memorable cold, winter morning in 1984 I witnessed an unusually large number of very bright meteors that seemed to radiate from a spot near Bootes. I counted forty-seven of them in a half hour. As soon as I got home and did a little research, I found out I had seen the Quadrantid meteor shower at its best.

I have even learned to love the Full Moon, because it lights up the ground early, particularly in Arizona, which does not follow daylight-saving time. The zodiacal light is splendid then, and even though dark skies are quickly lost, sunrise is always beautiful.

I have also found that getting up early to exercise has conditioned me for those important astronomical occasions when I have to get up or go to bed at odd hours.

Will you become more enthusiastic about astronomy if you become an early morning runner? Of course! I must admit, though, that it is sometimes agonizing for me to get up early. However, I am in better physical condition than I would be otherwise and the associated astronomical rewards are great. I have learned a lot about the sky and enjoy my hobby much more. Try it for yourself. The beauty of the predawn universe awaits you. — *Tim B. Hunter*

THE NEVER-ENDING NOVA HUNT

"Marv, I've really found something this time."

Silence on the other end of the phone line. This wasn't the first time I'd called Marvin Baldwin, the eclipsing binary chairman of the American Association of Variable Star Observers, to ask him to travel forty-five minutes to see what I'd discovered.

"It's bright, bright enough to be plotted on the AAVSO atlas."

Again silence.

I thought I had found a nova. It appeared out of nowhere in some pictures of a variable I was studying in Cassiopeia. However, by the time Marv arrived to see my photos, I realized the Cassiopeia/Perseus border cut through the corner of the photograph that contained my "nova." Sure enough, there is a long-period variable at this location in Perseus. Another false alarm!

My nova hunting had started in 1985 when I purchased a Celestron 8. I had been an amateur astronomer for ten years, but with the C8 I intended to delve into astrophotography. While experimenting with different exposure times, I ran across what looked like a star but wasn't on my other photos. By the time I figured out I had "discovered" a film flaw, I decided I wanted to search for novae with my camera.

Included with my new C8 was Ben Mayer's *Starwatch*, which included instructions for building a simple device with two slide projectors called a PROBLICOM (PROjection BLink COMParator). With the comparator you can project two photographs of the same area of sky, taken on different dates, on to a single surface. A cardboard shutter spins in front of the projection lenses, rapidly switching the view from one photo to the other. Anything that changes brightness or moves appears to blink.

After my first "discovery" I repeatedly photographed different areas of sky and compared the slides with my PROBLICOM. It wasn't long before I was "discovering" lots of things, like asteroids, artificial satellites, and variable stars.

Most people would have been discouraged by so many false alarms. I *was* discouraged, but I didn't give up.

On Sunday, the day after my most recent nova fiasco, I shot an entire thirty-six exposure roll of film. I developed the film on Monday and found a bright variable star that was not on any atlas. Tuesday morning I was on the phone again talking to Marv.

"Marv, I've found something."

Silence.

"It's bright, bright enough to be plotted on the AAVSO Atlas."

Again silence.

"Marv, it's not orange or red, it's white. The only other white variable I've found was an eclipsing binary, remember?"

"Give me the coordinates!"

The star I found, SAO 095781, proved to be the brightest large-amplitude Algol-type eclipsing binary found in fifteen years. Its parameters are nearly record breakers: an amplitude of 1.8 magnitudes, an eclipse duration of twelve to fourteen days, and a period of 3.45 years.

I still haven't found any novae. And I'm still having false alarms. But I am having fun and, occasionally, I've made a real discovery. — *Daniel H. Kaiser* ☐

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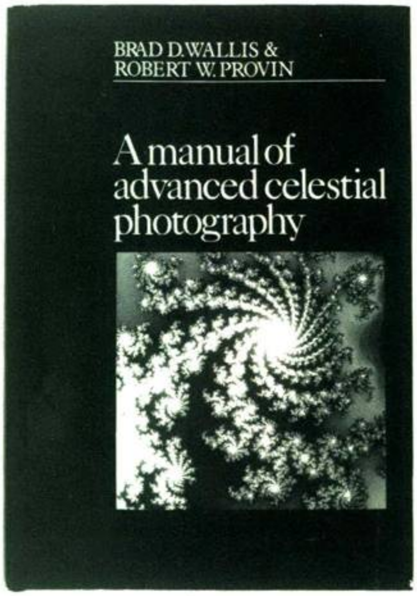

BRAD D.WALLIS &
ROBERT W. PROVIN

A manual of
advanced celestial
photography

A Manual of Advanced Celestial Photography by Brad D. Wallis and Robert Provin, (Cambridge University Press, 1988), ISBN 0-521-25553-8, hardcover, 388 pages, $39.50.

There are many books on astrophotography available today, and most of them are in the You-Too-Can-Take-Astrophotos genre. This book, however, does not fall into that category. This is a manual for the serious photographer — heavy on theory and technique and definitely not intended to get one started photographing the night sky. It is a comprehensive work, an assemblage of facts, figures, tests, and practical experiences from two of the more noteworthy members of that select cadre of amateurs whose work often graces the pages of this magazine.

More than half of the book is devoted to "setting up." These first chapters discuss instruments, techniques for using them, photographic theory, film characteristics, darkroom techniques, special treatments, and so forth. They should all be read and digested before you attempt to shoot any film.

The remainder of the book highlights techniques for deep-sky and planetary photography, provides a gallery of fine examples of the work of many of today's most noted practitioners, and contains several short sections on specialized subjects, such as cool-emulsion and planetary photography, by the likes of Jack Newton and James Rouse, acknowledged specialists in their chosen fields.

The chapters dealing with photographic theory and darkroom technique are superb. There is a certain discipline that must be practiced when handling film. Many of the most acclaimed photographers of our time, like Minor White and Ansel Adams, carried this idea to an almost Zenlike extent, but it is nonetheless an important part of the subject.

Exactly *how* film works is still a mystery even to film manufacturers, so it is important to approach any photographic process with a sense of wonder and humility. There are many secrets that will be revealed to those who take the time to understand the method. Techniques for squeezing every bit of information out of the photographic process are discussed at some length as well, and while many of them are beyond the reach of most of us, it is still instructive to understand how they work. It is in this realm that I found the book most useful.

The book is not entirely without its faults, though. The chapter on instrumentation is thorough but lacks diagrams that would help clarify some of the key points. There are also some inconsistencies in terminology. For example, in discussing the transmission characteristics of interference ("nebula") filters, the point is made that a faster f/ratio system will shift the peak transmission wavelength of light to "a lower wavelength than desired." Do the authors mean *longer* wavelength or lower *frequency*? The accompanying diagram is of little help. While the diagram shows the wavelength *increasing* as the f/ratio becomes smaller, the caption states just the opposite case.

Perhaps the most unsettling aspect of the book is a pervasive air of mild condescension on the part of the authors. They have undoubtedly put an enormous amount of time and effort into this book, and for the most part it shows well. However, there are some places (the preface, for example) where they seem to imply that astrophotography would not progress had the book not been written. Many amateurs might find this attitude a little discouraging. While I agree that you should strive to improve your work to the limits of your equipment and expertise, I also feel that there comes a point where the enjoyment of the subject is overwhelmed by the drive for technical perfection. After all, astrophotography is supposed to be fun!

These points aside, though, this book *fills an important* niche. It contains a wealth of material that should be of benefit to seasoned veteran astrophotographers as well as those who aspire to be more accomplished. Even professional photographers could learn a thing or two about custom film processing and printing techniques. Although newcomers would be better off with a more basic book, anyone who has the desire to record the heavens on film should consider keeping this volume handy. — *Geoffrey R. Chester*

HANDY ASTROPHOTO GUIDE

Astrophotography Basics, (Eastman Kodak Co., 343 State Street, Rochester, NY 14650-0811, 1988), Kodak Publication No. P-150, paperback, 24 pages, $2.

If you have a camera and want to take nighttime sky pictures, this is probably the best low-price guide available for getting started. Simple, well-written, and clearly illustrated, the pamphlet tells you how to photograph star trails, use an equatorially mounted telescope for photos, and how to capture lunar and solar eclipses on film.

In twenty-four pages there isn't a lot of room for extras, so the book's explanations tend toward the cut-and-dried. But the how-to aspects are covered fully. An exposure guide is provided in the middle of the book to help you better assess the f-numbers and exposure times for different film speeds, subjects, and instruments. If you really want to get involved, two pages in the back are devoted to lists of books and articles (many of the latter from ASTRONOMY) on astrophotography, telescopes, and amateur astronomy in general.

The book's only drawback — but a natural one given that it comes from the Great Yellow Father — is that the only films mentioned are Kodak's. Even so, you won't go wrong with Kodak films, and you'll soon discover which Fuji and Konica ones you can substitute. Book shops probably won't carry this pamphlet, so try a photo store or write to the Kodak company. — *Robert Burnham*

VARIABLE STAR OBSERVING

Observing Variable Stars: A Guide for the Beginner by David H. Levy, (Cambridge University Press, 1988), ISBN 0-521-32113-1, hardcover, 192 pages, $19.95.

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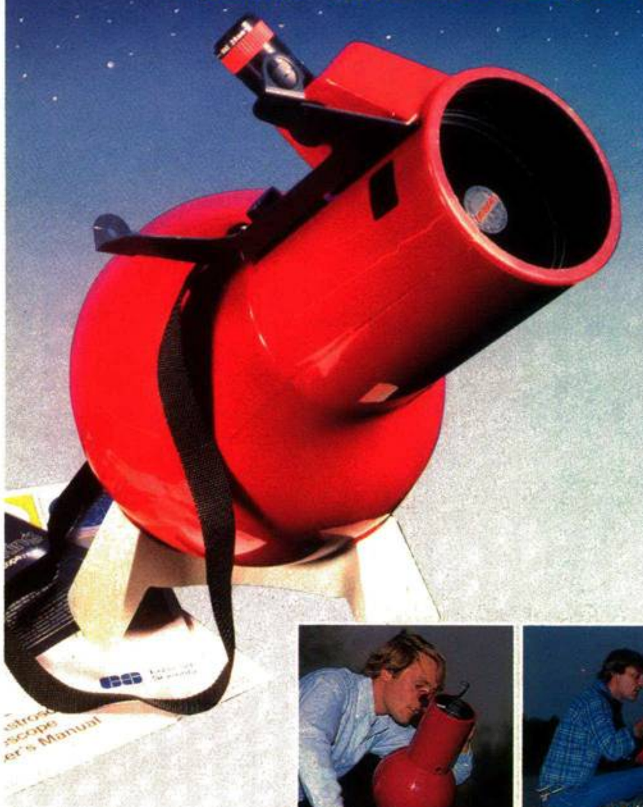

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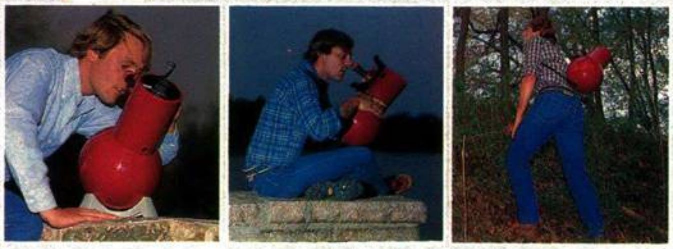

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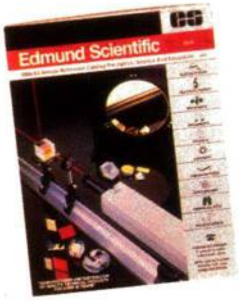

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camera, photoelectric photometer, and other instrumentation to complement the visual work. It is not an overstatement to say that the only substantive distinctions between professional and nonprofessional observers have to do with the sources of their incomes and the availability of sophisticated equipment. They all love what they do.

David Levy, an active observer of both variable stars and comets, makes a strong effort to recruit new members to this field. To paraphrase his words in the introduction, he wants to inspire the reader to observe variable stars by sharing his enthusiasm and concentrating on observing while keeping the scientific explanation simple and in the background. There are several good scientific books on the subject that the nonspecialist can read to supplement the material presented here, but, as a simple introduction to variable stars and a guide for the novice observer, this volume has no rival.

The book is divided into four parts. Part one deals with the constellations, basic properties of stars, types of equipment, and approaches to training the eye. In part two we meet the various classes of variable star and some bright examples of these classes that the reader can readily observe. Levy carefully discusses how to find the variable and estimate its brightness and how to process and report the results. He provides many helpful observing hints and describes many of the factors that can influence the results. Most devotees of this activity will recognize these factors, which include wind, clouds, light, curious bystanders, mosquitoes, police, dew, and so forth.

Part three discusses more interesting variables in each constellation, arranged by season. Part four consists of a section on "stars and people," notably John Goodricke, Leslie Peltier, and the American Association of Variable Star Observers community; information on available books and magazines (though missing is Michel Petit's fine but expensive book on variable stars published in 1987 by John Wiley) and on variable star organizations; a glossary of terms; and tables of the Greek letters and constellation abbreviations.

The two outstanding virtues of this book are the quality of writing and the consistency of presentation. The beginner will have no problem understanding the points the author is making and is very likely to be responsive to his obvious enthusiasm. Levy successfully mixes the technical and human aspects of variable star observing and the reader is treated to a number of historical digressions that are educational in themselves.

The human aspects of many important discoveries, including the author's own, illustrate many of the principles described.

As an example, he describes how he noticed — and almost missed — the bright nova in Cygnus in August 1975 and then later met a group of amateurs at a local observatory who were absorbed in examining M39 in the telescope without noticing the brightest nova in thirty-three years a few degrees away. They had used setting circles!

The author's advice on observing procedures and principles is almost always quite sound, though some could have been more effectively elaborated upon. He rightly indicated how useful common binoculars can be, especially as a beginner's instrument, and this reviewer can attest to the fact that there are literally hundreds of interesting variable stars that can be usefully studied by observers so equipped. I would have liked to see a more detailed discussion of the importance of magnification in determining what and how much can be seen in a given instrument. And although Levy does describe the magnitude scale, it would have been useful to indicate the faintest stars visible in binoculars and telescopes of various apertures and magnifications.

For a number of stars described, AAVSO charts are shown that the beginning observer can practice with. However, for most stars, the only charts given are large-scale maps showing stars down to about 6th magnitude and the positions of the variables marked with crosses. These maps are pretty useless for finding the many variables that don't reach 6th magnitude. Nor is specific advice given on how to procure proper charts, though the clever reader might note the AAVSO address given in the last section. Even with such charts the beginner might share this reviewer's disagreement with the author's opinion that the fields of AY and CY Lyrae are easy to find.

In fact, Levy seems to generally underestimate the difficulties that many, if not most beginning observers have not only identifying the variables and surrounding comparison stars but also relating chart orientations to what they see through their telescopes. Though not unique to variable star observing, these difficulties have undoubtedly turned many away from this fascinating activity.

In addition to the usual quota of typos, there are a number of less readily explainable errors in the text. On page 8, absolute magnitudes are given for the Sun, Sirius, and S Doradus, all of which are wrong, in the last case something like ten magnitudes! The brief description of dwarf cepheids is also incorrect. The visual magnitude ranges given for U Camelopardalis, WZ Cassiopeiae, RW Cephei, and DY Vulpeculae seem to be photographic ones and thus much too faint, and that for TV Geminorum is also incorrect. The maximum magnitudes for GK Persei and Eta Carinae are too bright, and no mention is made of the near-constancy in recent years of the cepheid RU Camelopardalis.

The discussion of Gamma Cassiopeiae indicates that the star is currently near 3.0 magnitude, whereas that was its minimum brightness following its 1936 maximum and it has been sitting near 2.2 magnitude for many years. The most unusual error appears to be the description of the star SW Andromedae, indicated in all the catalogs as a 0.44-day RR Lyrae star. In the text it is described in some detail as a long-period (37-day) eclipsing binary. Finally, while the author deserves some latitude in the choice of stars to mention, there are some notable absentees, especially in the far south (e.g., R Horologii, Kappa Pavonis, RR Telescopii).

These problems, however, are only relatively minor blemishes on what I regard overall as a successful effort. Someone looking for an introduction to observing variable stars will find here an entertaining, informative, and sympathetic guide. And if you weren't already looking at variable stars, you should start! Levy's enthusiasm is likely to lead you down the garden path to your telescope or to a dark-sky location where a pair of binoculars will expand your universe. You will then join a fortunate and select fraternity that has become aware of all the exciting things going on in the sky every night. — *Wayne M. Lowder*

ASTEROIDS

Asteroids: Their Nature and Utilization by Charles T. Kowal, (Halsted Press, a division of John Wiley & Sons, 1988), ISBN 0-470-21230-6, hardcover, 152 pages, no price given.

ASTROPHYSICS

Cauldrons in the Cosmos: Nuclear Astrophysics by Claus E. Rolfs and William S. Rodney, (University of Chicago Press, 1988), ISBN 0-226-72457-3, paperback, 561 pages, $45.95.

Laboratory and Space Plasmas, edited by Hiroshi Kikuchi, (Springer-Verlag, 1989), ISBN 0-387-96839-3, hardcover, 657 pages, no price given. ☐

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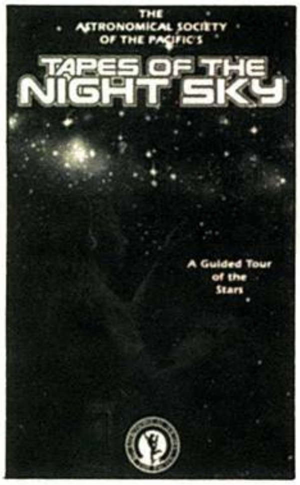
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Chroma-Scan Pocket Filters, (Cole Enterprises, 40714 East Acacia Avenue, Hemet, CA 92344), neutral density set, $8.95; colored set $12.95.

Anyone who's squinted at a painfully bright Moon or tried to discern colored features on Mars or Jupiter will welcome these handy sets of filters. The filter cards measure 3 by 5 inches and are plastic laminated for durability (except the actual filter circles); the filters are made from acetate and measure ¾ inch in diameter.

The three neutral filters have densities of 0.3, 0.6, and 0.9, which give transmissions of 50, 25, and 13 percent, respectively. This offers a range wide enough to reduce lunar glare to comfortable levels — even Full Moon as seen with a big Dobsonian. These filters also work well with bright planets like Jupiter and Venus.

The color filter card has eight filters spanning the spectrum from violet to red. According to the manufacturer, the violet filter is approximately equivalent to a Kodak Wratten #36. In the same way the blue is a #48, the light blue a #47, the green a #55, the yellow/green a #13, the yellow a #12, the orange a #21, and the red a #25. Given what you'd pay for all these filters individually, the assortment on the card offers you a real savings.

Glass filters that screw into the eyepiece are preferred for the most distortion-free views, but apart from considerations of cost, such an arrangement is very inconvenient when you wish to switch rapidly from one filter to another. These filter cards, which you hold between your eye and the eyepiece, therefore score highly on convenience, but users should be careful not to handle them roughly. Being acetate, they are tougher than standard gel photo filters, but they can still be scratched. Each card comes with a simple instruction sheet that tells you how to clean the filters without damage.

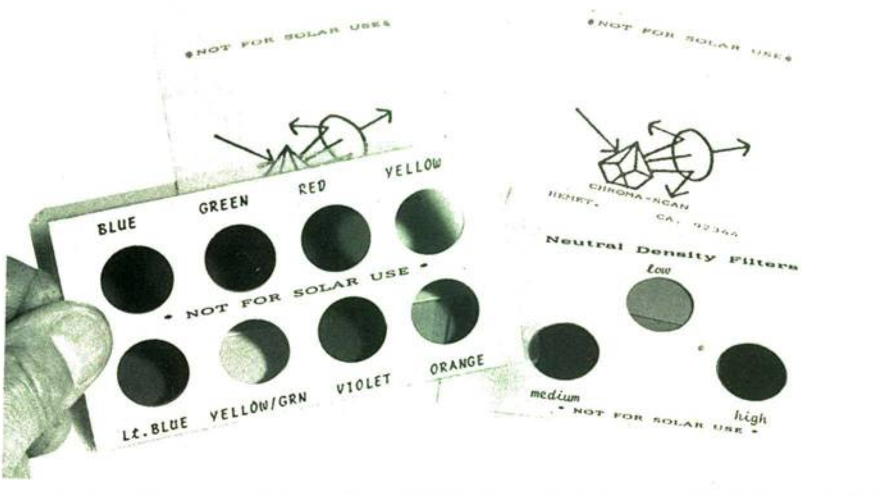
The manufacturer provides bulk discounts for organizations that want to resell the cards or give them away and will specially imprint the cards with any message. — *Robert Burnham*

MOON SLIDES

The Moon Kit: An Introduction to the Moon by Sherwood Harrington, (Astronomical Society of the Pacific, 390 Ashton Avenue, San Francisco, CA 94112; 1988), 18 slides plus 23-page booklet, $24.45.

To pack the Moon into an eighteen-slide collection is a daunting task. I tried to come up with my own short list of candidate images and quit when the number ran higher than thirty. The difficulty in compilation is twofold: first, a lot of Moon pictures have been taken, and second, we know a great deal about the place. The first means you have heaps of "must" images to include and the second demands that you tell the full story. Unfortunately this set, even given that it's limited in size and that it's an "introduction," offers less than one could wish for.

The set has two slides showing the whole lunar disk from Earth and a third



SIMPLE AND EASY TO USE, Chroma-Scan Pocket Filters are filters-on-a-card that let you switch rapidly from one filter to another at the eyepiece.

with a map of the far side. The rest of the set is best shown by the titles of the slides: King crater, rays from Copernicus, Eratosthenes crater, highland and mare compared, Silver Spur peak, Aristarchus plateau, Schroeter's Valley, astronaut at Hadley Rille, Marius Hills, *Surveyor 3*'s footprint, Moon rock (breccia), microcrater on glass bead, *Apollo* command and service module, *Apollo* lunar module, and man on the Moon.

This sounds good, but the map of the lunar far side covers only the area between 50° north and south, and, what's really fatal, not a single feature is labeled Most of the photos appear to be copies on color film of black-and-white originals, but the slides in the review set often do not maintain an even color balance and at times the color is completely false. In the photo of Eratosthenes, for example, the shadows are so twilight-blue that the Moon appears to have an Earthlike atmosphere! It's very pretty, but it isn't even remotely real.

Regarding sharpness, my guess is that most buyers would want a lunar slide set to feature lots of crisply rendered geological details so they can pore over the slides minutely when projected. Unfortunately the reproduction in several slides isn't quite sharp enough to allow this. Contrast too can be a problem: in the King crater slide, highlights are washed out. The cropping of this slide could also be improved, as a lava pond of some geological interest right outside the rim is cut into.

The photo of a Imbrium breccia (the lunar version of a conglomerate rock) doesn't show the individual fragments as well as other published photos of breccias have. Also, the last three slides show scenes from the *Apollo 11* mission. They are nice mementos, but they don't tell me anything about *the Moon*.

The booklet, in some ways better than the set it accompanies, contains basic information on lunar phases, exploration, and surface geology, and it includes captions to the slides. The booklet concludes with one of those great lists of books and articles for further reading that the ASP is deservedly famous for.

I think the society would have a real winner here if it increased the number of photos to about forty and selected and reproduced them with a little more care. There are *hundreds* of photos in NASA's archives that simultaneously inform you about the Moon, display great pictorial qualities, and have the kind of richly portrayed detail that invites you to play planetary geologist on your own. The lack of them makes this set a disappointment. — *Robert Burnham* ☐

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Meetings and Events

March 18
New England Astro-Fest #2, Farmington, Connecticut. Commercial astronomy equipment exhibition, sponsored by New England Astro-Optics, Inc. Contact: New England Astro-Optics, Inc., Attention: Astro-Fest #2, P.O. Box 834, Simsbury, CT 06070.

April 6-9
Pacific Planetarium Association Spring Conference, Yosemite National Park, California. Contact: Edna DeVore, Independence High School Planetarium, 1776 Education Park Drive, San Jose, CA 95133. Phone: (408) 729-3911.

April 7-8
35th Anniversary Celebration of the University of Illinois Astronomical Society. Contact: A.F.I.C., Astronomical Society, 349 Astronomy Building, Urbana, IL 61801.

April 28-30
3rd Annual Southern Star Conference, Blue Ridge Mountains of North Carolina. Hosted by the Charlotte Amateur Astronomers. Contact: Heather Fisk, P.O. Box 220234, Charlotte, NC 28222. Phone: (704) 332-4670.

April 29
43rd Annual Convention of the North Central Region of the Astronomical League, Rockford, Illinois. Hosted by the Rockford Amateur Astronomers, Inc. Contact: Carol Beaman, 6804 Alvina Road, Rockford, IL 61103. Phone: (815) 962-6540.

May 5-6
Arkansas Star Party, Sugarloaf Mountain, near Fort Smith, Arkansas. Sponsored by the Arkansas-Oklahoma Astronomical Society. Contact: Larry Kennedy, Route 3, Box 421W, Pocola, OK 74902. Phone: (918) 436-2204.

May 5-7
Astronomy Weekend, Blackwater Falls State Park, Davis, West Virginia. Contact: Pat Northeimer, Blackwater Falls State Park, P.O. Davis, WV 26260. Phone (toll-free): 1-800-CALL WVA.

May 12-13
Astronomy Fest '89, Roberson-Kopernik Observatory, Vestal, New York. Sponsored by the Kopernik Astronomical Society. Contact: Roberson-Kopernik Observatory, Underwood Road, Vestal, NY 13850. Phone: (607) 772-0660.

May 13
16th Annual Astronomy Day. Contact: Gary E. Tomlinson, Astronomy Day Coordinator, Astronomical League, Chaffee Planetarium, 54 Jefferson Avenue SE, Grand Rapids, MI 49503. Phone: (616) 456-3985.

May 13
Astronomy Day Celebration, Hoffman Estates, Illinois. Sponsored by the Northwest Suburban Astronomers. Contact: Bob Long, 4960 Chambers Drive, Barrington, IL 60010. Phone: (312) 991-7432.

May 19-21
Royal Astronomical Society of New Zealand Conference, Invercargill, New Zealand. Sponsored by the Southland Astronomical Society, Inc. Contact: Darryl Jones, Southland Museum and Art Gallery, P.O. Box 1012, Invercargill, New Zealand.

May 20
9th Annual Summer Telescope Demonstration and Star Party, Oceanside, California. Sponsored by the Oceanside Photo and Telescope Astronomical Society. Contact: Penny Hauck, 1024 Mission Avenue, Oceanside, CA 92054. Phone: (619) 723-0684.

May 24-26
1989 I.A.P.P.P. Big Bear Symposium, Big Bear Lake, California. Contact: Roger DeYoe, 3416 Genevieve Street, San Bernardino, CA 92405. Phone: (714) 883-9807.

May 26-29
Riverside Telescope Makers Conference, Camp Oakes, Big Bear, California. Contact: Cliff Holmes, 8642 Wells Avenue, Riverside, CA 92503. Phone: (714) 689-6893.

May 27
Astronomy Day, New Mexico Museum of Natural History, Albuquerque, New Mexico. Contact: Bruce L. Levin, P.O. Box 54072, Albuquerque, NM 87153. Phone: (505) 299-0891.

May 29-June 4
Texas Star Party, Prude Ranch, Fort Davis, Texas. Contact: T.S.P. Registrar, Bobby Braley, Department "A," P.O. Box 386, Wylie, TX 75098.

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Readings and Resources

Venus Unveiled (page 26)

Planetary Landscapes by Ronald Greeley, (Allen & Unwin, 1987). A pictorial volume on solar system geography that includes a chapter on Venus.

Venus, edited by Donald M. Hunten, Lawrence Colin, T. M. Donahue, and V. I. Moroz, (University of Arizona Press, 1983). Written for the professional planetary scientist, this book nonetheless contains many readable review papers.

The Colors of the Stars (page 36)

Astronomical Observations: An Optical Perspective by Gordon Walker, (Cambridge University Press, 1987). A comprehensive technical account of current observational techniques used by astronomers, including those pertaining to spectroscopy.

Stars and Their Spectra: An Introduction to the Spectral Sequence by James B. Kaler, (Cambridge University Press, May 1989). Covers the fundamental properties of stars, atomic structure, and how stellar spectra are interpreted.

New Dobsonians (page 61)

"An Extremely Portable 17.5-Inch Dobsonian" by Ivar Hamberg, *Telescope Making #17*, Fall 1982. This article triggered the age of tube struts.

Galaxy Optics, 1880 South Flatiron, Suite A-1, Boulder, Co 80301. Sells large-aperture, high-quality mirrors.

"A 16-Inch Dobsonian on a Pursell Platform" by Tom Osypowski, *Telescope Making #24*, Fall 1984. Information on equatorial platforms.

Sky Designs, 4100 Felps, Suite C, Colleyville, TX 76034. Sells Dobsonian telescope kits.

Telescope Making #35, Winter 1988/89. A must for learning more about the new Dobsonians.

Observing Planetaries (page 68)

The Webb Society's Deep Sky Observer's Handbook, Volume 2: Planetary and Gaseous Nebulae, edited by Kenneth Glyn Jones, (Enslow Publishers, 1979). Part of a seven-volume series on deep-sky objects that provides observing notes.

CREDITS

Cover: painting by Jim Hervat; *page 4*: association of Universities for Research in Astronomy; *page 10*: courtesy of Andrew Fruchter and Jeff Hester (200-inch Hale telescope), Princeton University; *page 14*: courtesy of Johns Hopkins University; *page 16*: John L. Russell; *pages 18-21*: paintings by Paul DiMare; *page 26*: NASA/Ames Research Center; *page 27*: *Pioneer Venus* topography, NASA/Ames; *pages 28-29*: *Pioneer Venus* base map, NASA/Ames, *Venera images*, Soviet Academy of Sciences and JPL; *pages 36-37*: Jerry Schad; *page 38*: Ronald E. Royer; *pages 40-41*: diagram illustration by Thomas L. Hunt, spectra of O through G stars based on *Revised MK Spectral Atlas for Stars Earlier than the Sun* by W. W. Morgan, H. A. Abt, and J. W. Tapscott, (Yerkes Observatory, University of Chicago, and Kitt Peak National Observatory, 1978), spectra of K through M stars based on *An Atlas of Representative Stellar Spectra* by Yasumasa Yamashita, Kyoji Nariai, and Yuji Norimoto, (A Halstead Press Book, John Wiley & Sons, 1978); *pages 42 and 44*: illustrations by Thomas L. Hunt; *page 45*: Harold Moore; *page 54*: Dewey Vanderhoff; *page 57*: Stephen Edberg (1250mm f/10 Schmidt Cassegrain, Ektachrome 400 film, 10-second exposure), June 12, 1988; *page 58*: Red Spot meridian crossings courtesy of Jim van Nuland; *pages 62-63, bottom series*: Dave Kriege; *page 63, top*: Richard Berry; *page 64*: diagram by Thomas L. Hunt, *top right*: Ron Ravneberg, *middle pair*: Dave Kriege, *bottom right*: Richard Berry; *page 65*: Richard Berry; *page 66, left*: Ron Ravneberg, *top and bottom right*: Peter Smitka; *page 67*: Peter Smitka; *page 69, top*: Jack Marling, *inset*: Jack Newton (20-inch f/5 reflector, VR 1000 film, 30-minute exposure with a light-pollution filter), *bottom*: sketch by David J. Eicher (8-inch f/10 SCT at 100x); *page 70, top and middle*: Jack Marling (24-inch f/15 Cassegrain, Fujichrome 400 film, 22-minute exposure at top, 10-minute exposure in middle), *bottom left*: Martin C. Germano (8-inch f/10 SCT, 103a-F film, 20-minute exposure), *bottom right*: Jack Newton (16-inch f/5 reflector, 12-minute exposure); *page 74*: John Asztalos (12.5-inch f/9 telescope); *page 75, sequence at left and photo at bottom right*: Stephen M. Larson and Gary Rosenbaum (University of Arizona 61-inch Catalina telescope, red-light CCD images digitally filtered with the help of C. Slaughter and W. Schempp of Photometrics Ltd.), central meridians from top to bottom: 39°, 193°, 128°, and 300°, *Solis Lacus*: Donald C. Parker, *Hellas*: Jean Dragesco (24-inch f/15 Clark refractor at Lowell Observatory stopped down to 18 inches in aperture), October 2, 1988; *page 76, polar cap sequence*: Donald C. Parker, composite sketch: Daniel M. Troiani (12.5-inch f/5 reflector), *Mountains of Mitchell*: Donald C. Parker, August 25, 1988; *page 77, left*: Donald C. Parker, *middle and right*: Lee Keith (12.5-inch f/9 telescope, sketch made at 380x with a red filter); *page 78, top photos*: Donald C. Parker, August 30 and November 28, 1988, *bottom sketches*: Daniel M. Troiani (10-inch f/6 reflector at 374x and 430x); *page 79*: John Asztalos (12.5-inch f/9 telescope); *page 84*: Lance Oldham (28mm f/2.8 lens, Konica SRV 3200 film, 30-second exposure); page 85: Tim Printy (50mm f/1.4 lens, Fujichrome 400 film, 2-minute exposure at left, 50mm f/2 lens, Ektachrome 200 film, 15-minute exposure at right); *page 87*: Tim Printy (50mm f/2 lens, Fujichrome 400 film, 5-minute exposure); *page 90*: illustration by Greg Kot.

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ANNOUNCEMENT – Anyone interested in forming an astronomy club please phone Mike Jones at (509) 697-3439. Write to 607 West Orchard Avenue, Selah, WA 98942.

ANNOUNCEMENT – The Starsedge Astrophotography Club is looking for new members to enjoy the rewarding field of photography. Contact Dave Stiebitz, 138 North Windham Road, North Windham, CT 06256. Phone (203) 456-2098.

ANNOUNCEMENT – The Ancient City Astronomy Club meets the first Friday of each month at 8 p.m. in the First United Methodist Church on King Street in St. Augustine, Florida. Contact P.O. Box 546, St. Augustine, FL 32085-0546. Phone (904) 797-5704 or (904) 269-2602.

FOR SALE – Meade 2080/LX3 including declination motor and hand control. Perfect condition. Will sell for $1,150 including shipping. Contact Roger DeKing, 8407 Emerick Road, Baldwinsville, NY 13027-9061. Phone (315) 638-8846.

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